TOP PROJECTS

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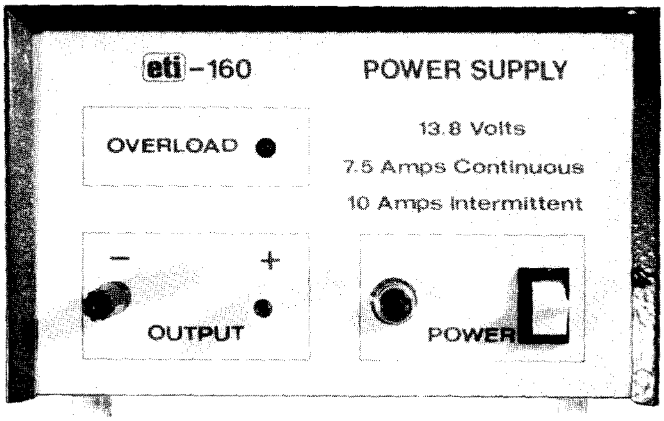
Project 160

13.8 V regulated high current supply



Here's a supply that's just the thing for operating transceivers, RF power amplifiers, etc, or anything that requires a 13.8 Vdc (nominal) supply and pulls more amps than the general run of 'CB' type power supplies can deliver.

Roger Harrison
Geoff Nicholls

MANY AMATEURS operate a mobile VHF or UHF transceiver at home as well as in the vehicle — it's convenient and economical. Until a year or so ago, most of these transceivers ran about 10 W output, drawing up to 2 A from the 12 Vdc (nominal) supply. Then transceivers delivering 25-30 W and incorporating multimode operation appeared on the market. These draw about 6-7 A from the 12 Vdc supply, and owners of 10 W output transceivers often add an 'afterburner' to boost the transmitter output. The ETI-710 (April '76) and ETI-716 (Jan. '78) 2 m booster amplifier projects provided around 40-45 W output on 2 m from a drive of 10 W, drawing around 7 A from a 12.5 V supply. A number of commercial amplifiers giving similar performance is available, too.

For novices, HF band transceivers, such as the Yaesu FT-7, are popular, but operate from a 12.5 Vdc supply. The FT-7 draws about 3.3 A on transmit, and similar transceivers from other manufacturers are much the same. Trouble is, the common 'CB'-type power supplies are generally rated to deliver only 2 A continuous, and while some will deliver up to 4 A intermittent, a 3 A load is too much for them.

Marine VHF FM band transceivers require a dc supply and, as they run 25 W, CB-type supplies are unsuitable if mains operation is contemplated for a base installation.

This power supply is intended to suit all the sorts of applications mentioned above — and any others you can think of where dc-operated equipment draws more than 3-4 A.

As most dc operated equipment is specified to operate from a 13.8 V supply, that's the output voltage we have settled on. The current rating we have quoted is based on several factors. Firstly, while the transformer specified has a secondary rating of 18 V/6 A, it is capable of delivering much more before the secondary output voltage loads down seriously. In addition, transformer temperature rise needs to be taken into account. Hence we determined a current rating by experiment, taking these factors into account, and it turns out to be 7.5 A. However, as much as 10 A can be drawn from the supply intermittently. At this point the regulator circuit cannot maintain output voltage, as the input-to-output differential begins getting a little too low. Short circuit current limit was set at this point too, for convenience.

No current meter was provided as this project was not intended as a test bench supply. The only indicators are a bezel lamp to indicate the supply is on and an 'overload' LED to warn that the supply has gone into current limit should you attempt to draw too much current or have a short circuit on the output.

Design notes

A capacitor-input bridge rectifier provides about 25 V input to the regulator circuit. This consists of a 12 V three-terminal regulator with output current being boosted by a pair of MJ15004 PNP bipolar power transistors connected in parallel. Current limiting is provided by a Darlington pair, Q1 and Q2, which senses the emitter current through the power transistors. When the current exceeds an amount determined by R2 (about 10 A), Q2 and Q1 turn on, Q1 robbing Q3 and Q4 of base current drive and preventing further increase in output current. When Q2 turns on, LED1 will turn on, providing indication of the overload condition.

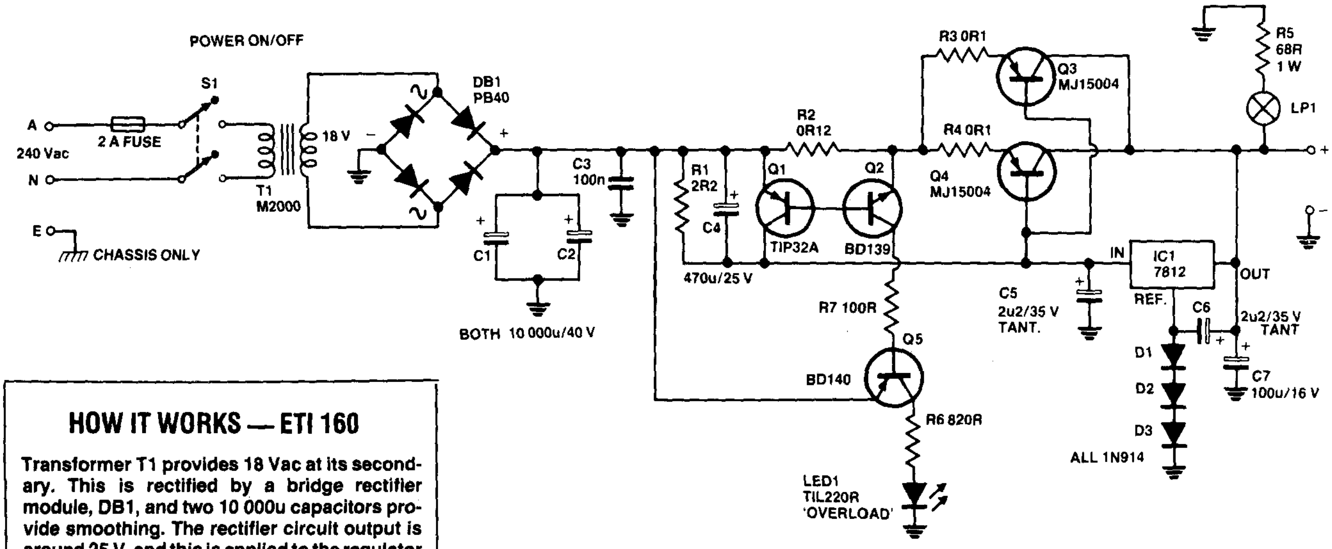
The output voltage is determined by the three-terminal regulator, IC1. Its reference terminal is 'jacked up' by 1.8 V by the drop across the diode string D1 to D3, resulting in an output voltage of 13.8 V.

Construction

We housed the power supply in a large K&W case, model C1064, measuring 155 x 155 x 255 mm overall. This has a U-shaped aluminium chassis with an etched front panel and four plastic feet that mount on the bottom. The case lid is steel, with ventilation slots punched in it and edges which wrap around the front and rear panels. It is secured by eight screws, four on each side panel. We made up a plastic Scotchcal stick-on label for the front panel.

Layout is generally non-critical, so components were placed in convenient positions. The heatsink carrying the major regulator components was mounted in a vertical position in the centre of the rear panel. The transformer was mounted on the bottom of the chassis, slightly to the right of centre, and the rectifier components were mounted to the rear panel. The overcurrent protection components were mounted on a small piece of matrix board on the bottom of the chassis, just to the left of centre and immediately behind the output terminals.

Unless you are purchasing this project as a kit with prepared metalwork, construction starts with the mechanical work. The heatsink should be tackled



HOW IT WORKS — ETI 160

Transformer T1 provides 18 Vac at its secondary. This is rectified by a bridge rectifier module, DB1, and two 10 000u capacitors provide smoothing. The rectifier circuit output is around 25 V, and this is applied to the regulator circuit, which consists of Q1 to Q4, IC1 and associated components. Q5 drives the overload indicator LED.

IC1 is a positive 12 V three-terminal regulator, such as a 7812 or similar. A parallel pair of PNP power transistors, Q3 and Q4, are arranged to boost the output current. A portion of the input current to IC1 flows through the base-emitter junctions of Q3 and Q4. Their collectors are connected to the output and, as they are operated here as current amplifiers, the load current supplied is much greater than the three-terminal regulator can provide. Resistors R3 and R4 ensure collector-emitter currents through Q3 and Q4 are shared equally. About 300 mA of the load current is contributed by IC1.

The reference pin of IC1 ('REF.') is raised by about 1.8 volts by the three series-connected diodes, D1, D2 and D3. They are forward biased by the bias current that flows from IC1's reference pin. Thus the output voltage is nominally 12 + 1.8 = 13.8 volts.

Over-current protection is provided in the following way: when the load current passing through Q3 and Q4 exceeds about 10 amps, the voltage across R2 will be about 1.2 volts. This will forward bias the base junctions of Q1 and Q2, which will turn on. When Q1 turns on, its collector-emitter junction effectively shunts the bases of Q3-Q4, robbing them of drive current and thus limiting their collector current. When Q2 turns on, its collector current forward biases the base-emitter junction of Q5, turning it on. The collector current of Q5 flows through LED1, which lights, indicating the overload condition.

For thermal protection, IC1 is mounted on the heatsink along with Q3 and Q4. Three-terminal regulators incorporate a 'thermal shutdown' mode where, upon reaching an internal junction temperature of 150°C, circuitry on the chip shuts off the output.

Capacitor C3 is a high frequency bypass for the regulator circuit input. Capacitor C4 prevents instability of the overload protection circuit. Capacitor C5 ensures stability of IC1, while C6 improves transient response. C7 provides a low impedance ac shunt for the regulator circuit output. Lamp LP1 provides indication that the supply is on.

Note that the chassis is not connected to the regulator circuit common rail, and the whole circuit 'floats', permitting negative or positive grounded equipment to be connected without fear of possible shorts between the equipment and the power supply.

SPECIFICATIONS ETI-160 POWER SUPPLY

Output voltage	13.8 Vdc
Output current	
continuous	7.5 A
intermittent	10 A
Regulation	
0-7.5 A	50 mV
10 A	1.3 V

first. Mark out and drill the heatsink according to the accompanying drilling diagram. When drilling the TO3 pattern for the MJ15004 transistors, drill the lower bolt clearance holes first and then use the transistor insulating washer as a template to mark out the positions of the emitter and base pins and the other bolt hole. The emitter and base holes can be drilled to whatever clearance suits you — say 3 mm or 5 mm.

Don't forget the mounting holes on the heatsink flanges.

Using the drilled heatsink as a template, place it on the rear panel of the case as centrally as possible, flanges down and with the fins vertical. Now mark the positions of the four mounting holes and drill them to 3 mm. Draw two lines on the case rear, diagonally between the mounting holes just drilled. Where they cross, drill a 9 mm or 10 mm hole and insert a rubber grommet in it (that's a ⅜" grommet — they don't seem to have gone metric yet).

The transformer mounting holes should be drilled next. Place the transformer in the bottom of the case, orientated as shown in our internal picture, about 10 mm or so from the rear panel and about 15 mm to the right of the approximate centre line (when viewed from the front). The grommet you just inserted marks the approximate centre line. Mark and drill the transformer mounting holes to 6 BA clearance (3 mm is fine). Next mark and drill the mains cable entry hole, the fuseholder hole and holes for the mains cable clamp and terminal block. We mounted the fuseholder above the mains cable entry hole. The terminal block and cable clamp were located in a convenient position adjacent to the transformer on the bottom of the case. Drill a hole for the mains earth lug-mounting screw near the rear corner foot-mounting hole. When the mains cable is installed, the earth lead will thus be the longest, ensuring it is the last to break should the mains cable become detached.

The front panel may be marked out and drilled now, using the artwork or Scotchcal as a template. You can lay the artwork directly on the front panel and prick through it with a scriber or other sharp-pointed instrument at the hole centres. Or, you could trace the hole centres on tracing paper and mark them in the same way.

Three more holes need to be drilled in the rear panel — two to mount the clamps that secure the filter capacitors, and one for the bridge rectifier. The two 10 000 uF filter capacitors are each secured to the rear panel with a 30 mm diameter cable clamp. They are a bit larger in diameter than the caps so we used a strip of double-sided sticky tape to build out the diameter so the clamps gripped effectively. The general mounting and wiring arrangement of the caps and rectifier is shown in the accompanying diagram. Twist the positive and negative leads of the caps together. The positive leads can be brought through the +ve terminal of the bridge rectifier, as we did, if you're careful.

The Scotchcal front panel may be mounted now. We used the plastic-type ▶

Scotchcal, but these need attaching with care to avoid bubbles and ripples. The way we have found best is to first peel the backing from one edge, align the label with the edge of the case and rub it down firmly. Then, peeling off the backing as you go, smooth the label onto the panel, taking it slowly to avoid bubbles and ripples forming. If you do get a bubble, try to smooth it towards the nearest edge to remove it.

Use a sharp knife or scalpel blade to cut the Scotchcal label away over the holes in the front panel. When this is finished, all the components that mount on the front panel can be attached: the two output terminals, overload LED, bezel lamp and mains switch.

Since there are relatively few components, we have used a point-to-point wiring technique rather than assembling most components on a pc board. The regulator components are soldered on a tagstrip mounted in the heatsink 'well' and between this and the device pins. The overload protection components mount on a small piece of matrix board, as can be seen in our internal photograph.

Mount the power transistors, Q3 and

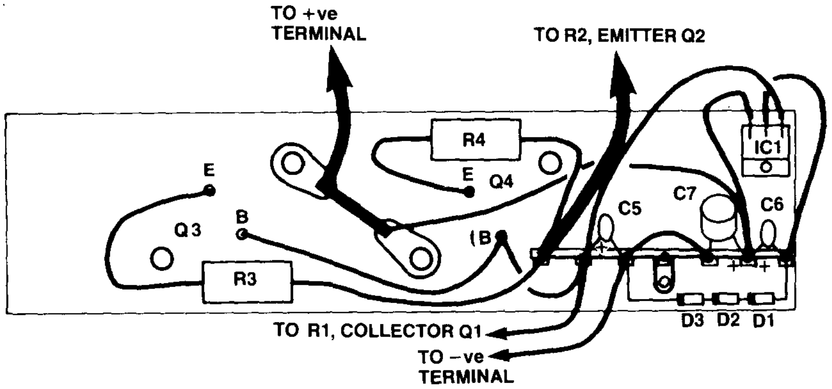
PARTS LIST — ETI 160

Resistors	**all 5%, powers as noted**
R1	2R2, 1W
R2	0R12, 10W
R3, R4	0R1, 5 W
R5	68R, 1W
R6	820R
R7	100R
Capacitors	
C1, C2	10 000u/40 V Elna RB electro.
C3	100n greencap
C4	470u/16 V RB electro.
C5, C6	2u2/35 V tant.
C7	100u/16 V electro
Semiconductors	
D1-D3	1N914, 1N4148, etc.
DB1	PB40, 40 A bridge rectifier
IC1	7812
Q1	TIP32
Q2	BD139
Q3, Q4	MJ15004
Q5	BD140
LED1	TIL220R

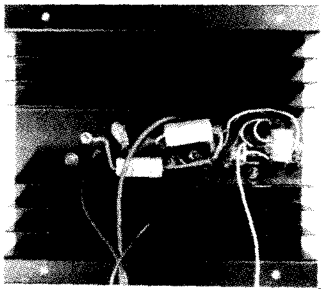
Miscellaneous

LP1 — 6 V/100 mA E.S. lamp; S1 — DPDT 240 Vac rated paddle switch; T1 — 18 V/6 A transformer, e.g: D.S.E M2000; case — K&W C1064; bezel mount for lamp LP1; LED mounting hardware; 240 Vac cable and plug; terminal block; two grommets; cable clamp; three tag strips; Scotchcal front panel; heavy duty terminals; 150 mm length of 45D6CB heatsink; transistor insulating washers, etc; 4 x 6 mm standoff pillars; nuts, bolts, wire, etc.

Price estimate
$72-$80

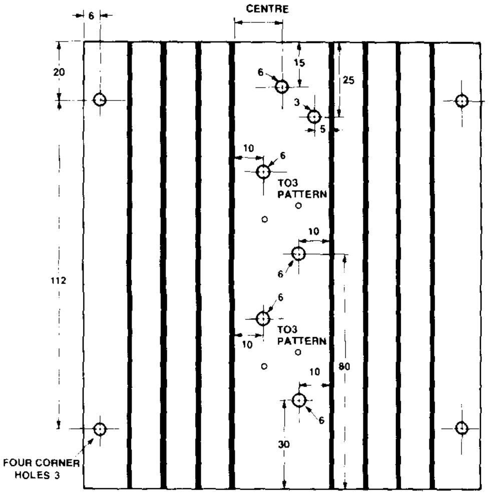


Wiring inside the heatsink.



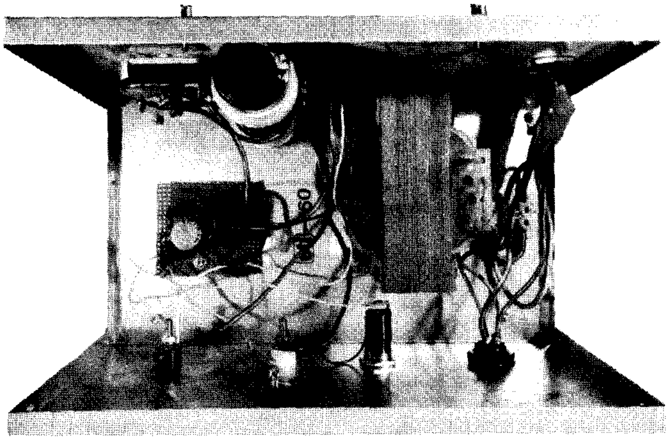
Inside the heatsink.

NOTE: Front Panel artwork for this project can be obtained by sending a stamped, self-addressed A4-sized envelope to:
Project 160 Artwork
ETI Magazine
140 Joynton Ave
Waterloo NSW 2017



13.8 V SUPPLY
HEATSINK DRILLING
VIEWED FROM MOUNTING SURFACE
SIDE OF HEATSINK
ALL MEASUREMENTS IN MILLIMETRES

Drilling the heatsink.



Inside the chassis, showing general component location.

Q4, and the three-terminal regulator, IC1, on the heatsink, along with the tagstrip. You'll have to bend up the legs of IC1 back over its body. Carefully deburr all holes on the heatsink first and use mica washers and insulating bushes to mount them. Smear the mica washers with thermal compound beforehand. Use solder lugs under the nuts on the two mounting screws nearest to one another on Q3 and Q4 — as shown in the accompanying wiring diagram for the heatsink components. With a multimeter, check that the cases of Q3 and Q4 and the tag of IC1 are not shorted to the heatsink. If they are, disassemble the offending device and fix the problem before continuing.

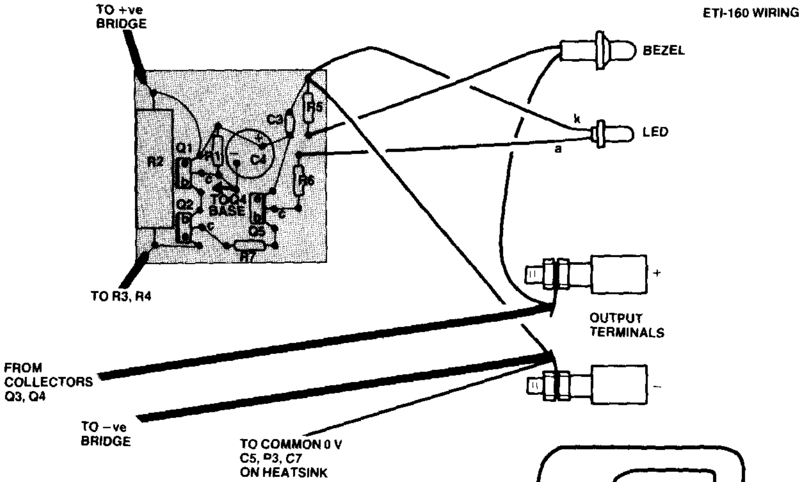
Solder the three 1N914 diodes (D1-D3) in series, with short leads between each, and solder them to the tagstrip as per the heatsink wiring diagram. Now solder C5, C6 and C7 to the tagstrip. Complete the wiring on the heatsink. Wire the collectors of Q3 and Q4 together using heavy duty hookup wire — preferably 32 x 0.2 mm. This point and the juncton of R3 and R4 should then have 250 mm lengths of heavy duty hookup wire attached, ready for wiring to the +ve output terminal and the emitter of Q2 respectively.

Two more wires run from the heatsink circuitry to inside the chassis — to the collector of Q1 and the +ve output terminal. Again, these should be 250 mm long, but only ordinary hookup wire is necessary. The heatsink assembly can now be mounted on the rear panel using 6 mm spacers.

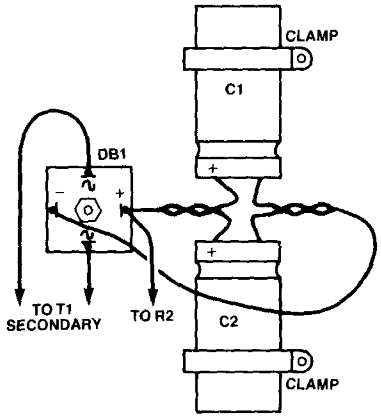
To mount the overload protection components we used a piece of matrix board about 55 mm square. General layout and component wiring is shown in the accompanying diagram. Remember to drill mounting holes in the matrix board and the bottom of the chassis. When completed, this board is mounted using 6 mm spacers.

Complete the construction by bolting in and wiring up the power transformer, the mains cable, fuse and switch, and the components mounted on the front panel. Note that it is important to use heavy duty hookup wire (at least 32 x 0.2 mm) between the filter caps' negative terminals and the −ve output terminal as well as from the rectifier's positive terminal to R2. Don't forget to bolt the four feet on the case.

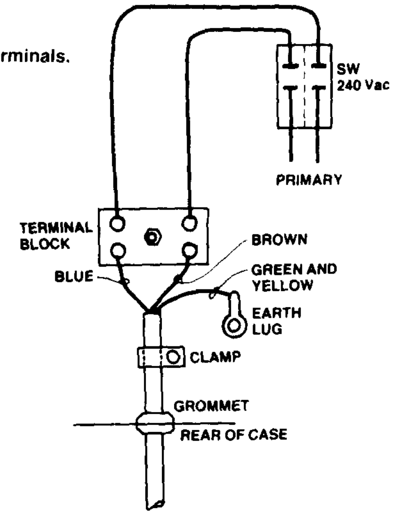
We used a 6 V/100 mA globe and a series resistor for the bezel lamp. You may have to change the value of the series resistor (R5) to accommodate globe rating. A 12 V globe could be used without a resistor, if you wish.



Wiring the overload components, bezel and output terminals.



Wiring the rectifier and filter capacitors.



Mains cable wiring. Be sure to sleeve all exposed connections for your own protection.

Testing it

Carefully check all your wiring. If you're satisfied all is well, plug in and switch on. The bezel lamp should light immediately. Check the output with a multimeter. It should read within ±100 mV (0.1 V) of 13.8 V. If not, switch off and trace the fault. If the output is around 25 V, you have a fault in the regulator wiring. If the output is greatly lower, look for faulty rectifier wiring, or even a faulty rectifier (rare). Generally, problems will be caused by a wiring error.

If the output voltage is OK, you can apply a load and see what happens. A 100 W load consisting of a single car light, or a combination to make up that power, will draw around 7.25 amps. The output voltage should drop no more than 50 mV.

If you can make up a load to draw 10 A (you'll need two multimeters for this one), check that the output does not drop lower than 12.4-12.5 volts.

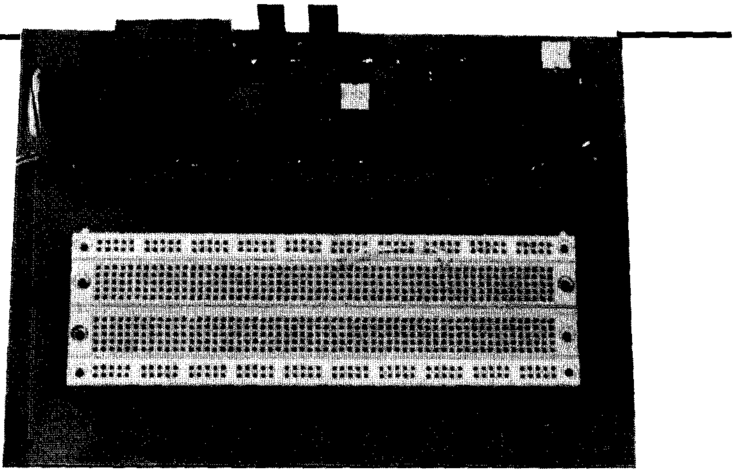
A multimeter capable of reading at least 12 A can be used to check the overload protection. Connecting the meter directly across the output terminals should result in a current of a little over 10 A (some 300-400 mA of the load current is contributed by IC1). This may vary somewhat, depending on the exact value of R2. If R2 is low, you may have to parallel another resistor across it to bring the overload current closer to 10.5 amps.

The overload LED should light when the load draws more than 10 amps.

When an overload remains on the supply for some time, the temperature of the heatsink will rise until IC1 reaches its temperature cutout point, at which stage it will turn off, turning Q3 and Q4 off, until the heatsink temperature drops. If the overload is still there when IC1 turns back on again, the process will be repeated until the overload is removed. This provides thermal protection to the unit. That's it!

We think you'll find this supply a very handy adjunct to the shack or workshop.

●



'Prototyper' breadboard

This is just the thing for lashing up circuits, experimenting with circuit techniques and component values, trying out circuit ideas, attempting circuit modifications, etc. If you're a dyed-in-the-wool experimenter, this project will be just your cup of tea.

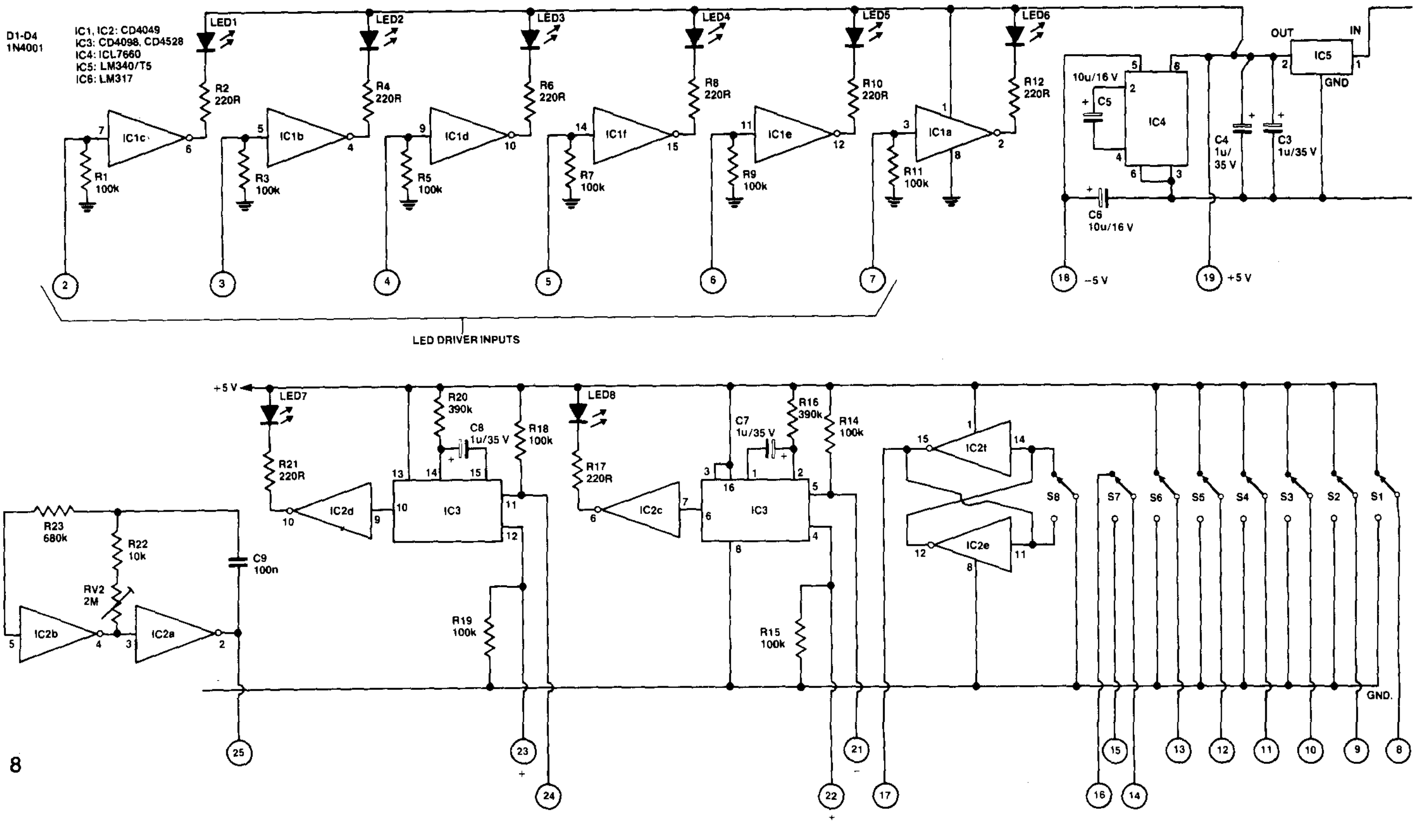
Graeme Teesdale

MANY HOBBYISTS have some form of 'patch board' or 'breadboard' used to mock-up circuits and make adjustments or modifications before laying out a printed circuit board. So many circuits only require a simple lash-up in order to 'prove' operation, but such lash-ups generally become monsters with power supplies, oscillators and whatever hanging off them all over the place. This project combines a number of useful pieces of test equipment on the one master printed circuit board. The unit is pretty well self-contained, with two fixed and one variable supply on-board, plus an oscillator, various indicators etc. Digital and analogue circuitry can be accommodated. It is powered from an ac plugpack — which keeps 240 Vac mains out of harm's way.

The overall size of the board is 200 x 155 mm, so it's quite compact. It fits readily into a briefcase . . . or even Roger Harrison's handbag! (— Eh? . . . Ed.).

The specifications table here lists the main features. The photograph at the head of the article shows the overall layout and construction. The pc board has been designed so that a 'breadboard' can be attached in the area toward the front. This consists of rows of pin sockets which accept transistors, ICs, wire and component leads, all arranged to make interconnection of components easy and logical.

Bus strips permit power supply connection. These are widely available and are known as 'breadboards', 'bimboard',



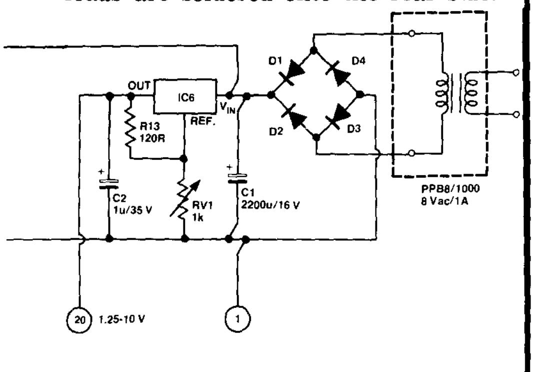
SPECIFICATIONS

Supplies	• +5 V @ 150 mA* • −5 V @ 18 mA • +1.25 — 10 V @ 100 mA* *more with heatsink on regulators, see text
Signal	• Variable frequency multivibrator — 3 Hz to 600 Hz
Sources	• Debounced, spring-return SPDT switch (for single-shot pulses)
Indicators	• 6 x buffered LEDs • 1 x positive-going, edge-triggered pulse indicator • 1 x negative-going edge-triggered pulse indicator
Switches	up to seven SPDT switches, contacts available

'breadboard socket', 'solderless breadboard', 'proto-board', etc. They are manufactured by firms such as Atek, Continental Specialities Corporation and others. You should be able to purchase one to suit this project for around $10 — $12. Make sure you get one that provides bus strips alongside the main breadboard for power supply connections.

Construction

The unit is constructed on a double-sided printed circuit board with components mounted generally on the uppermost side. The indicator LEDs and the switches mount onto the board and their leads are soldered onto the rear side.



The Klippon screw terminal strips mount on the topside of the board, the pin connections being soldered on the rear side. Links from the top to the bottom side provide interconnection between tracks on each side of the board.

Circuitry occupies a strip along the upper portion of the board, the row of LED indicators coming between this and the Klippon screw connector strip. The switches are arranged in a row on the lower edge of the board. The terminations on the screw connector strip are marked on the upper surface of the board, etched in copper. Each of the switches and LEDs is similarly marked. Each of the first six switches connects the switch pole to 0 V (logic low) in one position ('down'), and to +5 V (logic high) in the other position. The seventh switch has all three terminals 'free', while switch eight is a spring-return type hooked up to a debouncing circuit to provide one-shot pulses for manual clocking, triggering, etc.

It is recommended you purchase a ready-made pc board if you are not experienced at making your own pc boards. For those who wish to tackle the board themselves, remember that it is double-sided as you will need to take particular care with registration to ensure board holes line up from top to bottom.

Commence assembly by carrying out a visual inspection of the pc board, looking for any shorts between adjacent tracks and (rarely) broken tracks. Check also that holes are drilled to convenient sizes for the LED mounting hardware, switches, etc. If your board is not drilled, then tackle the drilling first as it's difficult to do once you've mounted components to the board. LED mounting holes need to be drilled out to 6 mm diameter, but as switches vary we'll have to leave their hole sizes to you. ▶

HOW IT WORKS — ETI 145

There are five sections in the Prototyper: power supplies, LED drivers, pulse indicators, square wave oscillator and switches.

POWER SUPPLIES

There are three power supplies: +5 V and −5 V fixed supplies and a positive variable supply with a range of 1.25 to 10 V.

The Prototyper has been designed to work from an 8 Vac output plugpack, thus removing any 240 Vac mains connections from the pc board. A full-wave bridge rectifier (D1 — D4) and capacitor (C1) provide a 12.5 Vdc supply to the inputs of two three-terminal regulators, IC5 and IC6. IC5 is a positive 5 V regulator (7805, LM340/T5, etc), while IC6 is an adjustable positive three-terminal regulator (LM317, etc). R13 and RV1 provide a bias for the reference terminal ('REF.') of IC6, permitting adjustment of the output voltage over the range 1.25 V to 10 V.

Output decoupling capacitors (C2 and C3) are provided for each regulator, mounted physically close to the devices, to improve transient response and reduce supply interaction between devices where several power supplies may be hooked up to one circuit. Both three-terminal regulators have internal short circuit and thermal overload protection.

The −5 V rail is derived by IC4, an Intersil ICL7660 voltage converter. The operation of this device is explained in the panel elsewhere in this article.

LED DRIVERS

The LED indicators, comprising LEDs 1 to 4, are driven by CMOS inverters from a 4049 hex inverting buffer chip. LEDs may be directly driven from the output of a CMOS inverting buffer, providing the current is limited to about 15 mA, hence 220 ohm resistors are connected in series with each LED (R2, R4, R6, R8, R10, R12). The input state of each of these buffers is determined by a 100k resistor from input to 0 V. This ensures the inputs are low, and thus the LEDs off, when the buffer inputs are open circuit.

PULSE INDICATORS

To indicate the presence of narrow digital pulses which would not light a LED long enough to be seen, two monostables are connected as 'pulse stretchers'. IC3 contains two CMOS monostable multivibrators — either a 4098 or 4528 may be used here. They can be configured to provide stable retriggerable/resettable one-shot operation. The leading edge (positive-going) and trailing edge (negative-going) inputs are brought out to the input connector strip on-board (21 and 24), each having the appropriate resistor connected to +V or 0 V so that either input is enabled (resistors R14-15 and R18-19).

Timing of the 'stretched' pulses is determined by external RC networks — R16/C7 for IC3a and R20/C8 for IC3b. With the values chosen, the period is approximately 200 ms using the 4098; a small variation occurs with the 4528. With the latter, the 'reset' input is unused and connected to +V. Its 'disabled' operation can be observed when first switching power on. LEDs 7 and 8 will come on for the delay period, after which the circuit reverts to normal operation.

The 'Q' output of each monostable drives a LED (7 and 8) via buffers from IC2 (IC2c and d).

OSCILLATOR

A variable frequency astable multivibrator provides a signal generator or clock source. Two inverting buffers from IC2 (another 4049) are connected so that positive feedback is provided ~~via~~ C9. R23 aids stability, and the frequency of oscillation is principally determined by C9/R22/RV2. The time to complete one charge-discharge cycle is approximately 1.4 times the RC time constant — but this can vary quite widely due to a 3:1 ratio of the transfer voltage within the device specification.

The oscillator has been made relatively independent of supply voltage variations by using a resistor (R23) in series with the input to the first inverter (IC2b). The frequency of oscillation is adjusted by varying the RC time constant. In this circuit RV2 permits varying the frequency over about a 220:1 range — giving coverage from around 3 Hz to 600 Hz. The frequency range can be reduced by increasing the value of C9.

The oscillator output is on pin 29 of the screw terminal strip.

SWITCHES

Eight switches are provided for on-board; all are single-pole, double-throw types. Six (S1 to S6) are wired so that the pole switches between +5 V (logic high) and 0 V (logic low). One has all terminals brought out (S7), and one is connected to a debounce circuit (S8).

The debounce circuit employs two inverting buffers from IC2 cross-connected in a flip-flop configuration. One output from the flip-flop is connected to pin 17 of the screw terminal strip. This switch can be used as a debounced manual clock. Drive capability of the output is equivalent to two *DTL/TTL loads*, i.e: Vcc = 5 V, Vdl ≥ 0.4 V and Vdm ≥ 3.2 mA.

Next, insert and solder in place all the top-to-bottom wire links. These are marked with a '•' on the component overlay.

All the resistors may now be mounted on the pc board and soldered in place. Note that some have their leads soldered on both sides of the board, the lead acting as a through-hole link. The four rectifier diodes can come next, followed by the filter capacitor and bypass capacitors C1, C2, C3, C4 and C6. Take care with the polarity of these capacitors and the diodes. Again note that some have leads soldered both sides of the board.

Mount the two voltage regulator ICs, IC5 and IC6, next. It is useful to bend their leads so that the rear of the metal tabs on these ICs is in line with the edge of the pc board. Then you can attach a heatsink to them later if more current consumption is called for on the fixed +5 V rail and/or the variable supply. A 60 mm length of 25 x 25 mm aluminium angle bracket would make a fine heatsink and permit current outputs up to two or three times the currents specified.

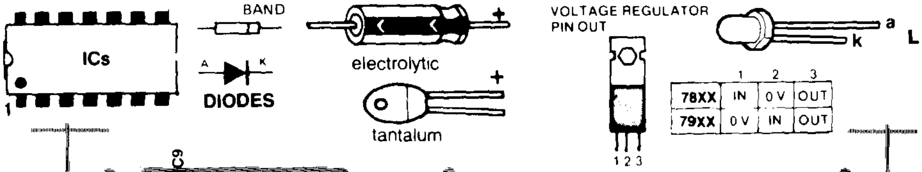
The variable supply trimpot, RV1, can be mounted now, along with the ICL7660 chip (IC4) and C5. Watch the orientation of the IC and the capacitor.

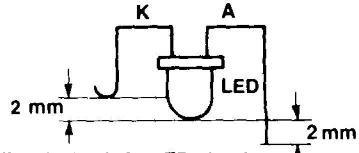
Power can now be applied for a test, if you wish. Check the supply voltages at the screw terminal strip pads. The two 5 V rails should be at 5 V ±0.1 V, and RV1 should provide an output from the variable supply that ranges between 1.25 V and 10 V. If RV1 is mounted correctly, a *clockwise* rotation will cause the variable supply output to *increase*. On no load, the voltage of the −5 V rail should be very close to 5 V (within 100 mV either way). Placing a 470 ohm resistor on its output as a load will cause the output voltage to fall to around 4.3 V, which is fine.

Mount the three remaining capacitors, taking care with the polarity of C7 and C8. The hardware for mounting the LEDs can be assembled to the board next. Prior to mounting the LEDs, each should have its lead formed as per the diagram here.

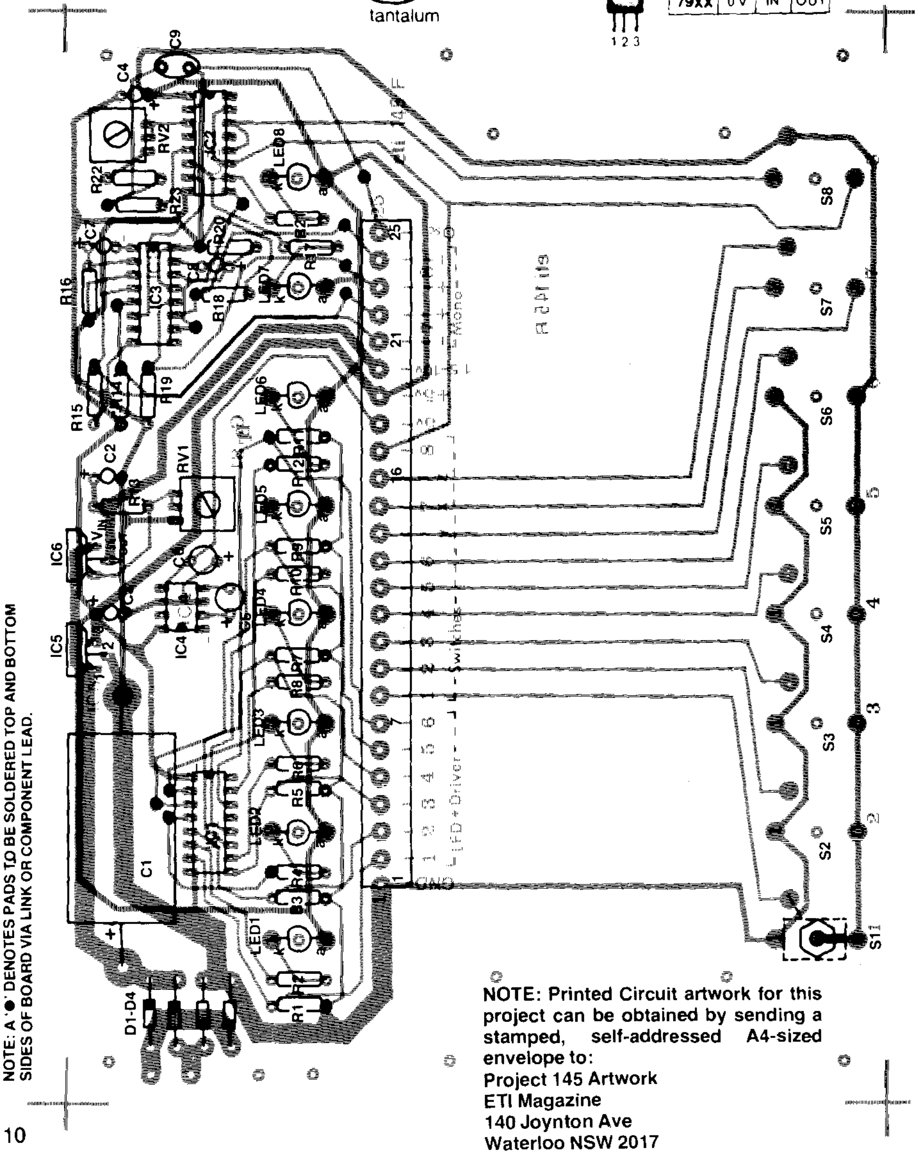
The cathode lead (K) should be bent and trimmed as shown, the anode lead being left longer and straight so that it provides a link to the +5 V rail when soldered on the top side of the board. When inserting the LEDs, make sure this lead protrudes through the top side of the board.

Now ICs 1, 2 and 3 can be mounted. Watch orientation and only handle them by their ends when inserting ▶





Bending the leads for LEDs 1 to 8.



NOTE: A '•' DENOTES PADS TO BE SOLDERED TOP AND BOTTOM SIDES OF BOARD VIA LINK OR COMPONENT LEAD.

NOTE: Printed Circuit artwork for this project can be obtained by sending a stamped, self-addressed A4-sized envelope to:

Project 145 Artwork
ETI Magazine
140 Joynton Ave
Waterloo NSW 2017

PARTS LIST — ETI 145

Resistors	**all ½ W, 5%**
R1, 3, 5, 7, 9, 11, 14, 15, 18, 19	100k
R2, 4, 6, 8, 10, 12, 17, 21	220R
R13	120R
R16, R20	390k
R22	10k
RV1	1k 'Helitrim' trimpot
RV2	2M 'Helitrim' trimpot
Capacitors	
C1	2200u/16 V axial electro.
C2, 3, 4, 7, 8	1u/35 V tantalum
C5, C6	10u/16 V RB electro.
C9	100n greencap
Semiconductors	
D1-D4	1N4001, EM401 etc
IC1, IC2	4049
IC3	4098, 4528
IC4	ICL7660
IC5	LM340/T5
IC6	LM317
LED1-8	TIL220R or sim.
Miscellaneous	
S1 - S7	up to seven SPDT toggle switches (as required)
S8	SPDT spring-return toggle switch

ETI-145 pc board; one PPB8/1000 ac plugpack; two pc board mounting strip connectors — 'Klippon' type MK 8/10 or similar; one pc board mounting strip connector — 'Klippon' type MK 8/2 or similar; one pc board mounting strip connector — 'Klippon' type MK 8/3 or similar; one length of figure-eight flex; 4 x 12 mm standoffs; 4 x rubber feet or grommets; nuts and bolts to suit; one 'breadboard' strip — such as Atek type AT-2N, Bimboard (e.g. Dick Smith Catalogue No. P-4612) or Proto-board (e.g: Dick Smith Catalogue No. P-4614).

Price estimate $60-$70

them, avoiding touching the pins, as they are CMOS devices. Solder their supply pins first — pins 1 and 8 on ICs 1 and 2, pins 16 and 8 on IC3.

The only remaining components to mount are the switches, the screw connector strips and the breadboard strip. Refer to the overlay for wiring the switches. Now fix the figure-eight ac input flex to the board, looping it through the two holes near the rectifier diodes. This provides a very effective, yet simple, cable clamp.

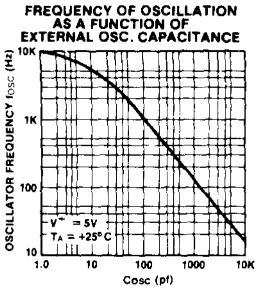
Connect the ac input cable to the PPB8/1000 plugpack and apply power. LEDs 7 and 8 should come on momentarily when you switch on. The LED driver and inputs can be tested by connecting switches 1 to 6 to the LED driver inputs 1 to 6. Putting a switch to '1' should cause the appropriate LED to come on. Switch 8 can be tested by linking it to one of the LED driver inputs. Holding SW8 on the '1' position will cause the appropriate LED to light. If anything doesn't work at this stage, make a careful wiring check, especially orientation of ICs and LEDs, and correct any faults.

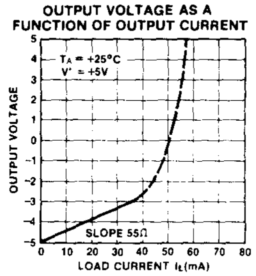
Once SW8 has been tested, it can be used to test the monostable inputs (marked 'Mono'). Link pin 17 (marked '8') to pin 21 (Mono '7', marked '-'). When SW8 is operated and released, LED7 will come on for 200 ms on the '1' to '0' transition. The reverse happens when you link SW8 to the '+' input, pin 22.

The last section to test is the square wave oscillator. Connect the 'Osc' terminal (pin 25, on the right hand end) to one of the LED driver inputs. Turn RV2 to the fully anti-clockwise position and the LED should flash at about a 3 Hz rate. To observe the maximum frequency, an oscilloscope is required, although you could couple the oscillator output to an audio amplifier (but remember the output is at quite a high level) and listen to the squeal produced. Varying the trimpot should vary the frequency.

That's it. Happy prototyping! ●

THE INTERSIL ICL7660 VOLTAGE CONVERTER





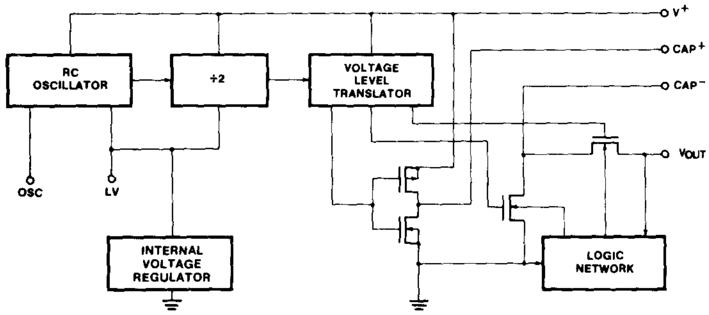


Figure 2. **Internal block diagram of the ICL7660.**

The Intersil ICL7660 is a monolithic 'MAXCMOS' power supply circuit which performs the complete supply voltage conversion from positive to negative for an input range of +1.5 V to +10.0 V, resulting in complementary output voltages of −1.5 to −10.0 V with the addition of only two non-critical external capacitors.

Contained on-chip are a series dc power supply regulator, an RC oscillator, a voltage level translator, four output power MOS switches, and a unique logic element which senses the most negative voltage in the device and ensures that the output N-channel switches are not forward biased. This assures latch-up free operation.

The oscillator, when unloaded, oscillates at a nominal frequency of 10 kHz for an input supply voltage of 5.0 volts. This frequency can be lowered by the addition of an external capacitor to the 'OSC' terminal, or the oscillator may be overdriven by an external clock.

The 'LV' terminal may be tied to ground to bypass the internal series regulator and improve low voltage (LV) operation. At medium to high voltages (+3.5 to +10.0 volts), the LV pin is left floating to prevent device latch-up.

The ICL7660 may be obtained in 8 pin DIL or TO-99 can packages, pin configurations being shown in Figure 1. The internal block diagram is shown in Figure 2.

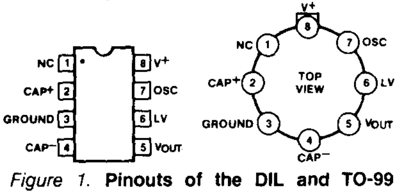


Figure 1. **Pinouts of the DIL and TO-99 packages for the ICL7660.**

FEATURES

- Simple conversion of +5 V logic supply to ±5 V supplies.
- Simple voltage multiplication ($V_{OUT} = (-)\,nV_{IN}$)
- 99.9% typical open circuit voltage conversion efficiency
- 98% typical power efficiency
- Wide operating voltage range 1.5 V to 10.0 V
- Easy to use — requires only two external non-critical passive components

APPLICATIONS

- On-board negative supply for up to 64 dynamic RAMs
- Localised μ-processor (8080 type) negative supplies
- Inexpensive negative supplies
- Data acquisition systems

CIRCUIT DESCRIPTION

The ICL7660 contains all the necessary circuitry to complete a voltage doubler, with the exception of two external capacitors which may be inexpensive 10u polarised electrolytic capacitors. The mode of operation of the device may be best understood by considering Figure 3, which shows an idealised voltage doubler. Capacitor C1 is charged to a voltage, V+, for the half cycle when switches S1 and S3 are closed. (Note: Switches S2 and S4 are open during this half cycle.) During the second half cycle of operation, switches S2 and S4 are closed, with S1 and S3 open, thereby shifting capacitor C1 negatively by V+ volts. Charge is then transferred from C1 to C2 such that the voltage on C2 is exactly V+, assuming ideal switches and no load on C2. The ICL7660 approaches this ideal situation more closely than existing non-mechanical circuits.

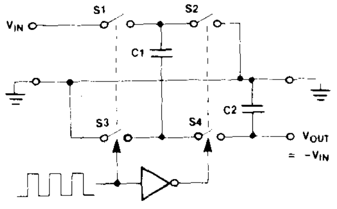


Figure 3. **Internal representation of how the ICL7660 works.**

The four switches in Figure 3 are MOS power switches; S1 is a P-channel device and S2, S3 and S4 are N-channel devices. The main difficulty with this approach is that in integrating the switches, the substrates of S3 and S4 must always remain reverse biased with respect to their sources, but not so much as to degrade their 'on' resistances. In addition, at circuit start-up and under output short circuit conditions ($V_{OUT} = V+$), the output voltage must be sensed and the substrate bias adjusted accordingly. Failure to accomplish this would result in high power losses and probable device latch-up.

This problem is eliminated in the ICL7660 by a logic network which senses the output voltage (V_{OUT}) together with the level translators, and switches the substrates of S3 and S4 to the correct level to maintain necessary reverse bias.

The voltage regulator portion of the ICL7660 is an integral part of the anti-latch-up circuitry; however, its inherent voltage drop can degrade operation at low voltages. Therefore, to improve low voltage operation the 'LV' pin should be connected to ground, disabling the regulator. For supply voltages greater than 3.5 V the LV terminal *must be left open to insure* latch-up-proof operation, and prevent device damage.

Project 1505

Fluorescent light inverter for 12 V battery operation

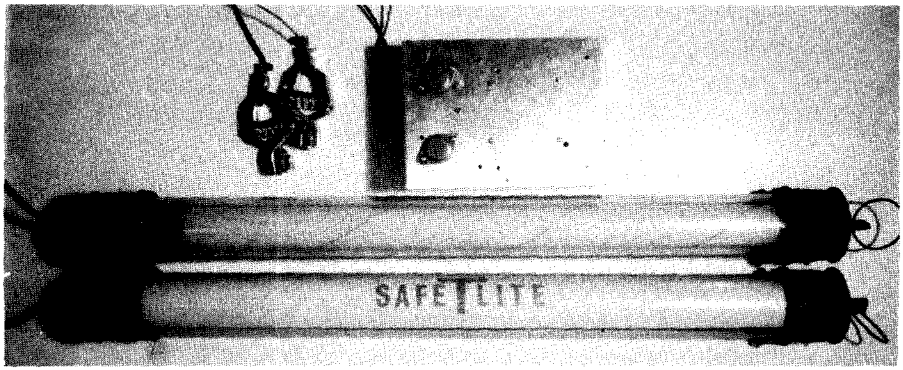
This inverter will drive two 20 W, one 40 W or one 20 W fluorescent tube from a 12 V battery. Light output is some three times that of an equivalent power incandescent globe and efficiency is very high.

David Tilbrook

WE FIRST published a fluorescent inverter in the November 1972 issue of ETI. It was a self-oscillating circuit, running at around 2 kHz, and was intended for use with a 20 W fluorescent tube and a 12 V battery. The circuit worked well, and countless numbers have been built over the years. The only disadvantage is the 2 kHz running frequency, which generates an audible tone that can be difficult to silence. Having decided to publish a new design, the main priority was to develop a circuit that would run above 20 kHz, making the inverter totally silent. However, this proved to be a much more difficult task than was first expected, and most of the initial prototypes failed miserably.

The main problems associated with running above 20 kHz are caused by losses in the cores and switching transistors, causing excessive heating and inefficiency. The circuit finally developed overcame these problems with the help of some cores from Philips that exhibit very low loss above 20 kHz. The problem with the switching loss was reduced by using BDY91 transistors, which have very low saturation voltages but fast switching speeds.

The circuit is a self-oscillating, saturating, push-pull inverter, similar in concept to the earlier design. The frequency of operation of these circuits depends on the number of turns on the primary of the transformer and on the properties of the core material. In general, if the primary turns are decreased the oscillation frequency is increased, since the magnetic field intensity necessary to cause core saturation occurs sooner, and core saturation causes the circuit to toggle to the opposite state. (A more detailed description of this is included in the How It Works section.)

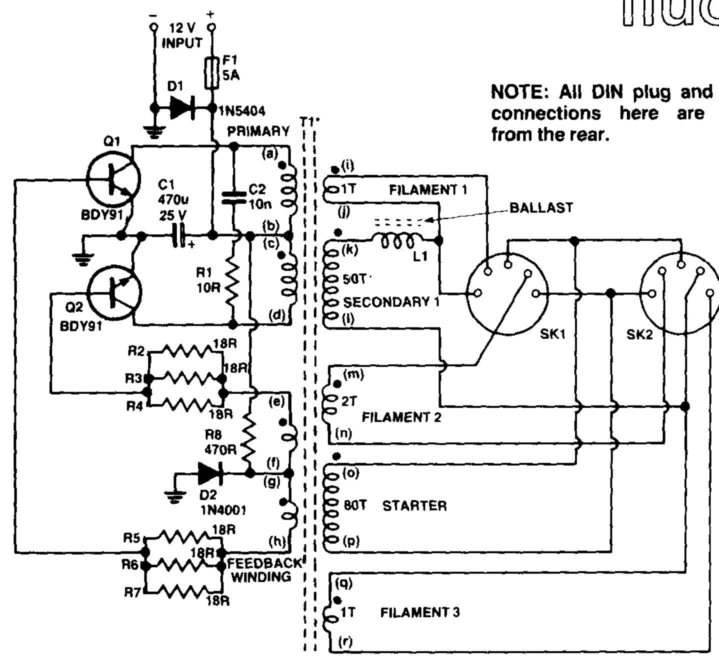


Our final prototype. We used two 20 W tubes housed in 'Safe-T-Lite' enclosures. Put protective plastic caps over the transistors to prevent shorts. One 'starter' wire (see circuit) can be seen wound around the top tube.

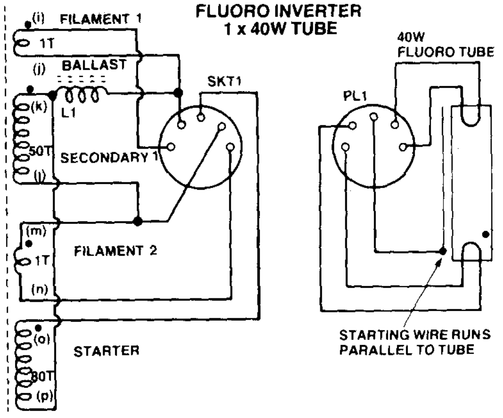
In the initial prototype designs we tried to use common potcores such as the FX2242 or FX2243. Unfortunately these have relatively large core loss above 20 kHz, and operation of the inverter for only 15 minutes caused core temperatures of well above 150°C. Furthermore, although it was possible to make the circuit oscillate above 20 kHz, this was achieved only by allowing the transistor to saturate in order to cause switching of the circuit. This was done by limiting the amount of base drive to the transistors so that when sufficient current flowed through the transistors a voltage drop would start to appear across them, causing switching. It was impossible to make the cores saturate before the transistors with a reasonable number of turns on the primary. The problem with this technique is that the increased voltage drop across the transistors causes an increase in the power dissipation in these devices, further decreasing the efficiency of the circuit.

The solution, as mentioned above, was to use a core capable of working above 20 kHz with negligible loss. We chose Philips EC52/24/14 cores as we had previously used them in the ETI-142 power supply (Feb. '79). They are commonly used in switch-mode applications and have been available for some years. See the 'Shoparound' page this issue for suppliers. The design uses four of these cores (they come in core halves), two for the main inverter transformer and two for the ballast inductor core.

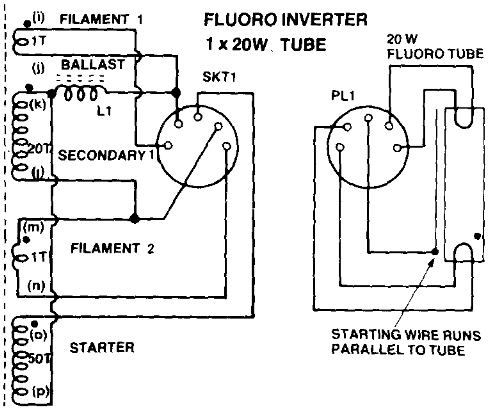
Fluorescent tubes, like most gas discharges, have a negative resistance and will pull extremely large currents if allowed to. To overcome this it is necessary to place an appropriate amount of impedance in series with the tube, limiting the current to a realistic value. A resistor of course cannot be used, since power dissipation would be enormous. Instead the ballast inductor is used, which has another advantage not immediately obvious. If the supply voltage to the inverter is decreased, by a slowly flattening battery for example, the frequency of oscillation and the output voltage will decrease. However, since the impedance of the ballast decreases at lower frequencies, the effect of decreased voltage is offset somewhat, and light output does not drop as much as expected. Similarly, if the voltage applied to the inverter is too



NOTE: All DIN plug and socket connections here are shown from the rear.

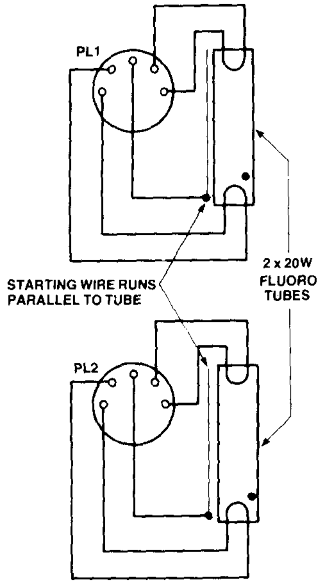


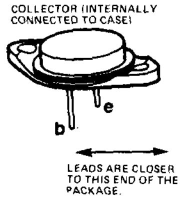
Arrangement for driving a single 40 W tube.



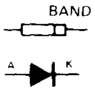
Arrangement for driving a single 20 W tube.

ABOVE: General circuit of the inverter, configured to drive two 20 W tubes, as in our final prototype.
BELOW: Tube wiring details. Note that they are connected in 'series'. The 'starter' wire brings about initial ionisation of the tube. It may be laid parallel to the tube or wound around it once or twice.





power transistors



DIODES

high, the oscillation frequency tends to increase, the impedance of the ballast increases, and once again the tube current is maintained closer to the optimum, ensuring good tube life.

This inverter can be configured to drive one 40 W tube, two 20 W tubes or one 20 W tube. However, the latter option is not recommended as actual power dissipation goes up! Battens for two 20 W tubes and for a single 40 W tube are readily obtainable from lighting suppliers and it is possible to build the inverter into these. We elected to have a pair of 'portable' 20 W tubes driven from the one inverter, constructed in a convenient aluminium box.

▶

HOW IT WORKS — ETI-1505

The circuit is a push-pull, self-oscillating inverter. The moment the supply voltage is connected, current flows through the 470 ohm resistor, R8, through the feedback winding and current limiting resistors to the bases of Q1 and Q2. One of these two transistors will turn on, as both devices are not exactly matched in characteristics, and force the other transistor to turn off. If, for example, Q1 turns on, current will flow through a-b of the primary winding. This causes a magnetic field to build up in the transformer core creating a positive voltage on d, h, j, l, n, p and r (i.e: the finish of each winding), the 'starts' being indicated by a ●). So, the base of Q2 is driven negative, forcing the transistor hard off. The base of Q1 is driven positive, driving the transistor hard on.

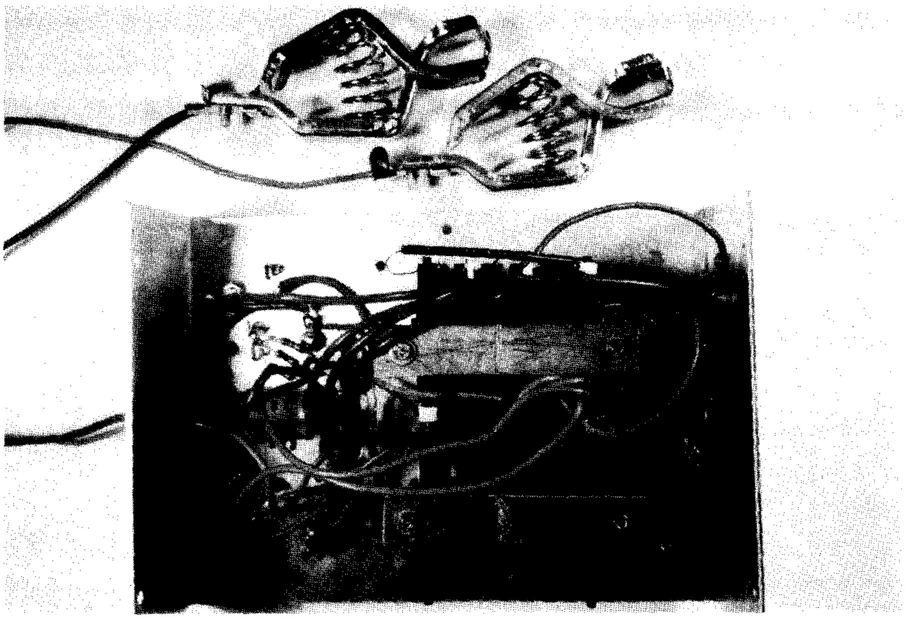
Since the primary of T1 acts as an inductor, the current flowing increases linearly for as long as the voltage is applied until finally the magnetic field intensity reaches a maximum, where the transformer core saturates. At this moment, the impedance of the core drops since the saturated core cannot maintain the relatively high inductance of the primary. The decreased impedance causes an increase in current flowing in the primary, driving the core even further into saturation until most of the coupling between coils on the transformer is lost. This causes the drive voltage to the transistor bases to disappear. Current stops flowing in the transformer and the magnetic field starts to collapse. This causes the voltage sense of each winding to reverse and the start (●) of each changes from negative to positive. This removes charge from the base of Q1, which turns off, and drives the base of Q2 hard on. The whole sequence of events then repeats itself, only Q2 is now hard on and Q1 is hard off.

In this way, the circuit oscillates at a frequency determined by the core material, the number of primary turns and the applied voltage.

Resistor R1 and capacitor C2 serve simply as a 'snubber' to remove flyback voltage spikes from the collectors of the transistors, preventing destruction of the devices by overvoltage. Diode D2 is incorporated to enable starting of the circuit but is 'transparent' during operation.

The transformer secondaries are wound to provide the necessary voltages for either 20 W or 40 W fluorescent tubes maintaining voltage and filament voltage. The 'starter' winding is necessary to ionise the gas in the tube to induce the tube to light. This could be done by increasing the secondary voltage but this causes an unnecessary current consumption in the primary. A separate starter winding is by far the better approach and the one we have used.

The ballast inductor L1 serves to limit the current flowing through the tube(s) which have a negative resistance characteristic and can draw very high currents once lit, if allowed.



Internal view of our final prototype inverter, showing general layout. The inverter transformer, T1, is at upper right, the ballast, L1, below it.

Construction

Best place to commence is with the hardware. We housed the unit in an aluminium case we had to hand that measured 170 mm long by 125 mm wide by 55 mm deep. This allowed plenty of room to mount everything. Any housing of a suitable size could be used, or the circuitry could be built into the base of a fluorescent light batten.

You'll need to drill TO-3 mounting hole patterns for the two power transistors (Q1 and Q2). Use an insulating washer as a template. The two transistors can be mounted adjacent to one another. We mounted ours 50 mm apart (between centre lines), toward one end of the box. The 7-lug tagstrip was mounted between them, toward the middle of the box, allowing plenty of room to mount the transformer and ballast in the area left. The two DIN sockets were mounted on the end panel, at the end of the box opposite the transistors. You'll need to drill suitable holes for the transformer mounting clamps. While the transformer assemblies are generally supplied with special mounting clamps, these may sometimes be unavailable. We didn't have any so fashioned some out of some 55 mm long bolts and a scrap of pc board for a top clamp (either remove the copper or cut it so that the bolts, chassis and clamp don't make a shorted turn around the core). When you're mounting transformer T1 later, its core should be separated from the chassis a little by a strip of cardboard or pc board. This reduces eddy current losses in the chassis and core and reduces chassis and core heating during operation.

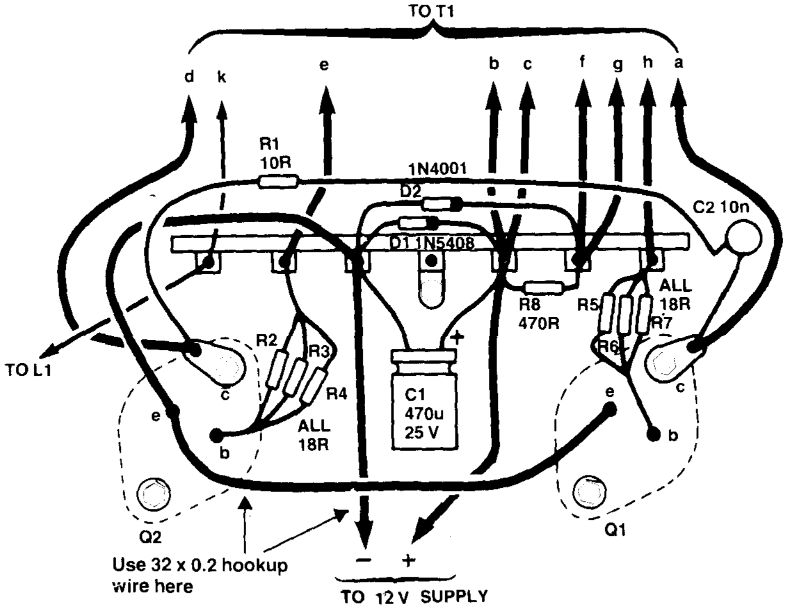
We leave the exact details to you as individual construction will likely vary considerably.

With the chassis drilled, mount the transistors first, using insulating washers, thermal compound and bushes for the mounting bolts. Put a solder lug under one mounting nut on each transistor (inside the chassis) for collector connections.

Next mount the tagstrip and solder in the resistors, capacitors, diodes and transistors, so far as possible. Refer to the wiring diagram.

Wind T1 and L1 next. Details are given in the accompanying panel. Having completed T1 and L1, assemble and mount T1 first. Sleeve all enamelled copper wire flying leads with spaghetti insulation. Make sure you can identify each lead. Wire up T1 according to the circuit and wiring diagram. Take particular care wiring up the DIN socket or sockets — depending on whether

General wiring diagram. Don't forget the line fuse in the positive 12 V supply lead.



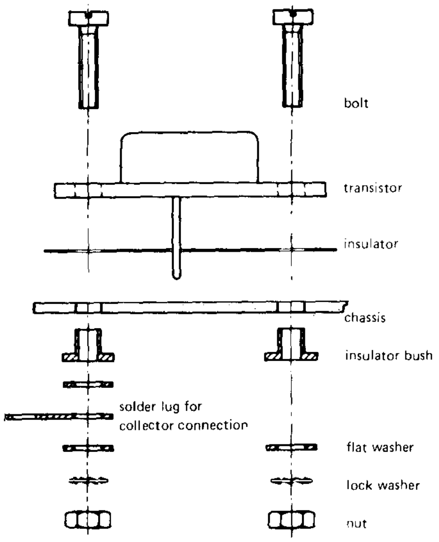
PARTS LIST — ETI-1505

Resistors	**all ½W, 5%**
R1	10R
R2, 3, 4, 5, 6, 7	18R
R8	470R
Capacitors	
C1	470u/25 V RB electro.
C2	10n ceramic
Semiconductors	
D1	1N5404 or similar
D2	1N4001 or similar
Q1, Q2	BDY91 or BDY92
Miscellaneous	
F1	5 A fuse and in-line fuseholder
PL1, PL2	5-pin DIN plugs
SK1, SK2	5-pin DIN sockets (chassis-mount)
L1	Philips EC-core assembly (windings — see text) 2 x EC52/24/14 cores (4322-020-52520) 1 x former, no tags (4322-021-33020) clamp assembly: 1 x 52PLATE, 1 x 55UBOLT, 2 x 632NC2A.
T1	as per L1

One 20 W or one 40 W or two 20 W fluorescent tubes; housing(s) to suit tube(s); case for electronics; one 7-way tag strip; battery cable (pair of 32 x 0.2); battery connectors; nuts, bolts, wire etc.

Price estimate $35 — $40

not including fluoro tubes and tube housing(s)



Mounting Q1 and Q2

you're using one 20 W, one 40 W or two 20 W fluorescent tubes.

Mount the ballast inductor, L1, but don't secure it in place too permanently yet as you'll need to set up the inverter by 'gapping' the core. Put spaghetti on the flying leads of L1 also.

Now the tube or tubes can be wired up. We used two 20 W tubes mounted in 'Safe-T-Lite' plastic tubes with rubber ends which we obtained from Warburton Franki. Some kit suppliers may be able to supply these along with kits. Wiring to the fluorescent tubes may be done with ordinary hookup wire — the filament pins may be soldered to directly. The 'starting' wire is attached to the tube with glue or tape. We used hookup wire run the length of each tube. It is not connected to any part of the tube. For the lead from the tubes to the DIN plugs, we used five-core double-insulated cable, which should not be too difficult to obtain.

Setting-up procedure

Before powering up, make sure the ballast inductor core halves are in good contact with one another. Now, plug in your fluoro tube or tubes, connect the inverter to a 12 V battery or power supply (it should be capable of 4-5 A), and switch on. The tube should light smoothly and you should be able to hear the inverter oscillating at around 12-15 kHz (if your ears are OK). If the tube doesn't light or the inverter doesn't oscillate, switch off and check your wiring. If all seems OK, reverse connections 'e' and 'h' on the feedback winding and power up again. This time the inverter should spring to life — if not, you still have a problem. Sort it out before continuing.

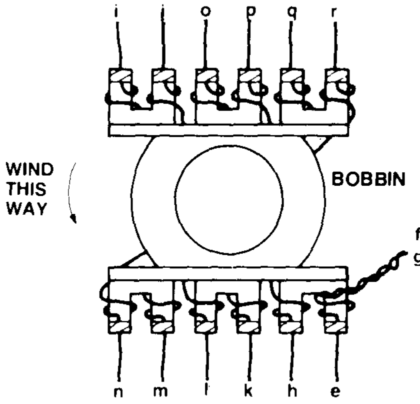
Assuming your inverter now works, you can proceed with adjusting the ballast inductor.

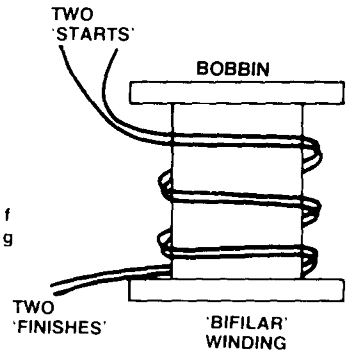
For correct operation, the inductance of L1 needs to be set by 'gapping' the core, limiting the maximum current through the fluorescent tube or tubes. To do this, insert an ammeter in series with one 12 Vdc supply lead, set to read 5 A (max.) if you have a 40 W load (one 40 W tube or two 20 W tubes), or 3 A (max.) if you have a 20 W tube.

We found the best gap was obtained by taking a small piece of paper, cut from a page of ETI, and inserting it between the faces of one 'leg' of the core halves! Clamp the assembly firmly. Then, apply power and measure the supply current. It should be within 100 mA of 4.5 A for correct operation on a 40 W load with a supply of between 12 and 14 volts. For a 20 W load, the current should be around 2.5 A.

That's it! May your little light shine brightly. ●

WINDING T1 AND L1





Components required:
Two Philips EC core assemblies, each consisting of:-
2 x EC52/24/14 cores — 4322-020-52520
1 x former, no tags — 4322-021-33020
1 x clamp assembly as follows;
1 x 52PLATE, 1 x 55UBOLT, 2 x 63NC2A

Wire required:
About 4 m of 0.4 mm dia. enamelled copper wire.
About 1 m of insulated hookup wire (10 x 0.2 mm).
About 1 m of heavy duty insulated hookup wire (32 x 0.2 mm).

L1: Wind 40 turns of 0.4 mm enamelled copper wire (about 1 m) on one bobbin, tieing off the ends to convenient posts on the bobbin end cheek. Spread the winding over the bobbin. Leave about 100 mm or so of lead length.

T1: Commence with the **'starter' winding** (o/p). For this you'll need about 120 cm of 0.4 mm enamelled copper wire. Referring to the accompanying drawing, tie off the start (o), leaving about 100 mm or so of lead. Wind on **80 turns,** spreading the winding over the bobbin. Tie off the end (p) adjacent to the start, as shown in the diagram, leaving another 100 mm or so of lead.

Do **secondary 1** next. This requires 0.4 mm enamelled copper wire. The number of turns required depends on which tube or tubes you intend to run. Consult the 'windings' table. As for the first winding, commence by tieing off the start (k) then wind on the required number of turns, spreading the wire over the former. Again, start and finish leads should be 100 mm or more.

Now wind the three filament windings. **Filament 1** and **filament 3** are each **one turn** of enamelled copper wire. **Filament 2** is **two turns.**

The feedback winding comes next. This is wound *bifilar* using the lighter duty insulated hookup wire (10 x 0.2 mm). Take a pair of wires, laid side by side, and wind **one turn** on the bobbin, tieing off the ends leaving long flying leads. Twist together one start and one finish for the centre tap (f & g).

An illustration of bifilar winding (showing three turns) is given in the accompanying diagram.

The **primary** winding comes last. This too is wound *bifilar,* using the heavy duty hookup wire (32 x 0.2 mm). Wind on **three turns,** tieing off the leads, leaving long flying leads as for the feedback winding. Twist together one start and one finish for the centre tap (b & c).

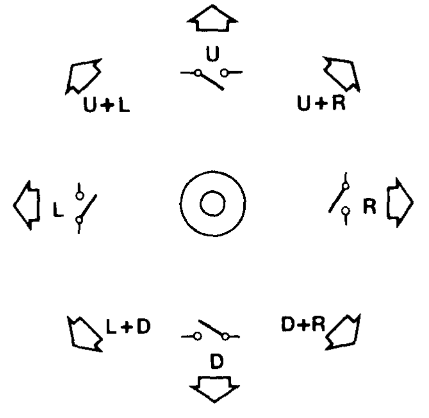
Windings
L1 40 turns, 0.4 mm enam. copper wire.
T1 **primary** (a-b, c-d)
3 turns, bifilar, 32 x 0.2 mm insul. hookup wire.
feedback (e-f, g-h)
1 turn, bifilar, 10 x 0.2 mm insul. hookup wire.
filament 1 (i-j)
1 turn, 0.4 mm enam. copper wire.
secondary 1 (k-l)
single 20 W tube: 20 turns, 0.4 mm enam. copper wire.
two 20 W tubes: 50 turns, 0.4 mm enam. copper wire.
one 40 W tube: 50 turns, 0.4 mm enam. copper wire.
filament 2 (m-n)
2 turns, 0.4 mm enam. copper wire.
starter (o-p)
80 turns, 0.4 mm enam. copper wire.
50 turns for 1 x 20 W tube
filament 3 (q-r)
1 turn, 0.4 mm enam. copper wire.

Atari-type joystick interface for the System 80

This simple add-on interface attaches to the System 80 expansion connector and permits attachment of an Atari-type joystick for graphics or games control.

Geoff Nicholls

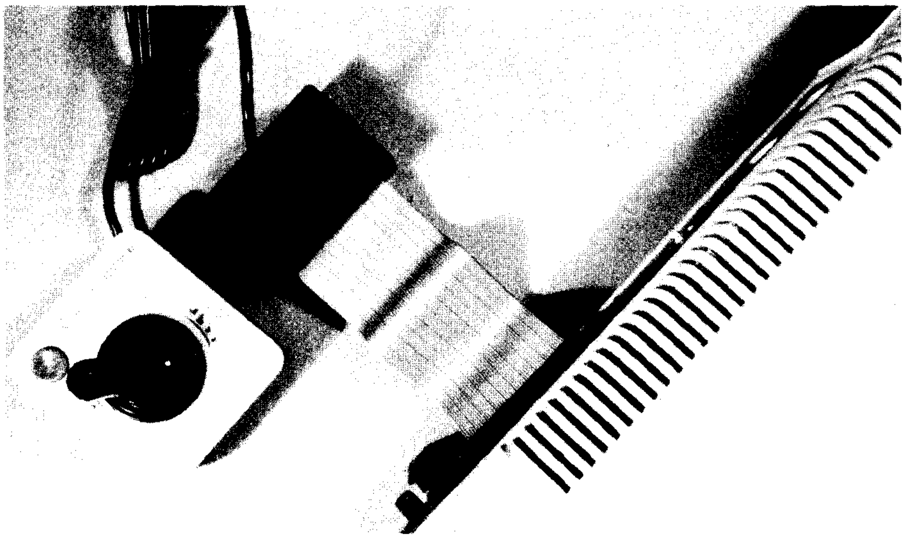
SOME OF THE popular cassette-based software suitable for the System 80, such as that by Big Five and Adventure International, calls for an Atari-type joystick input for controlling on-screen objects. This type of joystick has four switches arranged orthogonally and activated by a vertical shaft which is kept in the upright, or 'neutral', position by a rubber boot. You grasp the shaft with one hand and the base of the unit, containing the switches, with the other. Angling the shaft in any direction then activates a switch or combination of switches to indicate the direction of shaft movement. Eight directions can be indicated:



The 'directions' indicated by movement of the joystick shaft.

A button in the joystick base can be activated by the thumb to give another function — usually a 'write' or 'fire' function (as in games involving missiles, etc).

These joysticks first appeared with Atari TV games and latterly their home computers. The same type of joystick is available, under the Commodore label, for the Commodore VIC-20 home computer. Dick Smith lists the latter in his catalogue, No. X-2020, for $19.95.



The interface simply attaches to the System 80's expansion connector at the rear of the machine.

As it stands, the joystick is a '5-bit' device — four 'direction' bits and one 'fire' bit. Some joystick software requires '4-bit' input. In this instance, the U and D switches are paralleled by the fire button. A slide switch provides for both 4-bit and 5-bit modes of operation.

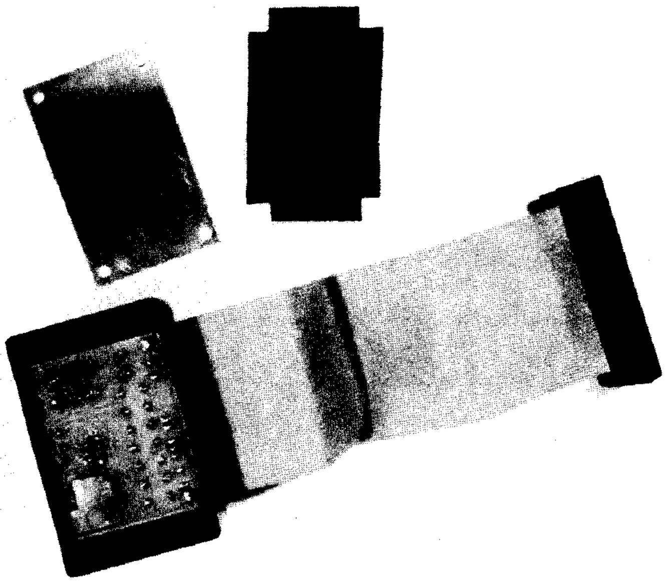
The interface is powered from the System 80.

Construction

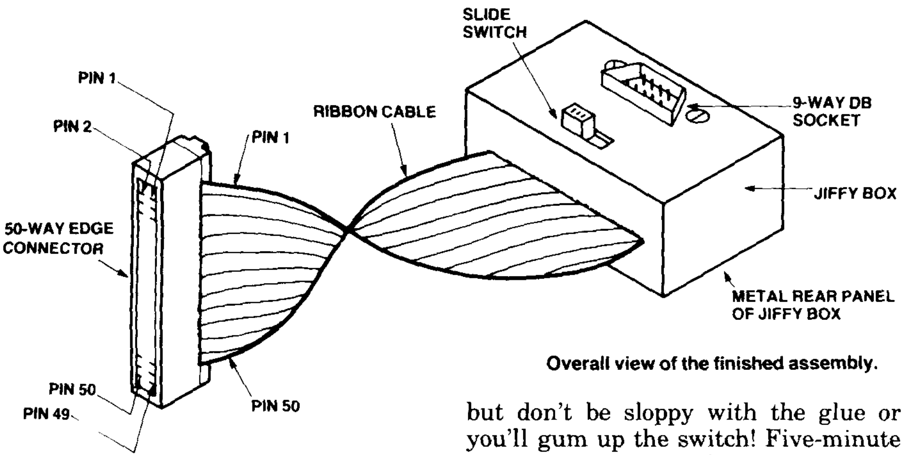
We recommend you use our pc board design as it simplifies construction and reduces the possibility of wiring errors. We fitted the pc board into a 28 x 54 x 83 mm jiffy box (Dick Smith catalogue No. H-2755). The 9-way chassis-mount plug for the joystick connector and the 5-bit/4-bit slide switch mount on the plastic base of the box (which now becomes the 'top'). Connection to the System 80 expansion interface is via a 50-way edge connector and a length of 50-way ribbon cable that passes through a slot cut in the side of the jiffy box to the pc board mounted inside.

Construction should commence with drilling and cutting the various holes in the jiffy box. Take your 'empty' pc board and, using it as a template, copper side down, mark the approximate position of the 9-way chassis-mount DB plug on the outside of the jiffy box bottom. Mark out the required hole for it and its two mounting screw holes, then mark out a suitable position for the slide switch slot, on the side opposite the 9-way plug. Drill out all of these and carefully file the 9-way plug hole and slide switch slot to shape so that both components fit neatly — *from inside the jiffy box.* A slot for the ribbon cable is cut in one side of the box. Drill a line of small holes and file the slot edges flat.

Before mounting the 9-way plug, solder 50 mm lengths of 22 gauge tinned copper wire to pins 1, 2, 3, 4, 6 and 8. These should drop straight down from the plug pins. Next solder a 75 mm length of three-way ribbon cable to the pins of the slide switch. Now both the 9-way plug and the slide switch may be mounted in the box. Bolt the 9-way plug in place. We glued the slide switch in —

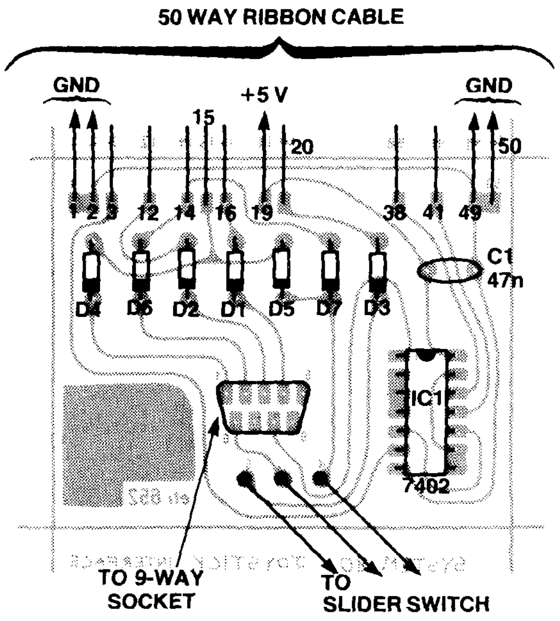


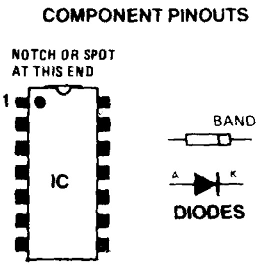
The pc board is held inside the jiffy box by the metal panel. Note the piece of insulating material that goes over the back of the board to prevent shorts.



Overall view of the finished assembly.

but don't be sloppy with the glue or you'll gum up the switch! Five-minute epoxy is very handy here, and is used later, as you shall soon see.





The printed circuit board artwork is on page 64.

Make up the ribbon cable and edge connector now. We used a 50-way edge connector that 'crimps' on the end of the cable, making contact to the wires without the necessity of stripping the insulation by means of special pins on the connectors. The other end of the ribbon cable is fed through the slot in the jiffy box for 50 mm or so. Identify the wires to be soldered — 1, 2, 3, 12, 14, 15, 16, 19, 20, 38, 41, 49, 50 — and cut back the unused wires about 25 mm. Strip the ends of the remaining wires about 5 mm and tin them. Put the box assembly aside for the moment.

Now the pc board can be assembled. The diodes, capacitor and IC can be assembled in any order — just watch the orientation of the semiconductors.

Having completed that, the ribbon cable can be soldered to the board — make sure the wires are in their correct places, though. It's worth a double check. The pc board has been laid out to make this part of the job relatively easy, however. Now wire in the slide switch. Adjust the ribbon cable such that the full 50 wires (i.e: the uncut section) protrude through the inside of the box about 15 mm or so. Run a bead of five-minute epoxy along the cable right at the slot and let it set.

After the epoxy has set, put 10 mm lengths of spaghetti insulation over the tinned copper wires on the 9-way plug. Feed the wires through the correct holes in the pc board (which should be pretty well beneath the socket when lined up to go in the box) and push the board into the box. Straighten the wires by pulling them gently with pliers and solder each of them. Cut a piece of thin cardboard or plastic to fit over the rear (copper side) of the pc board to stop the metal lid from possibly shorting the tracks. Put this in place and secure the lid. ▶

PARTS LIST — ETI-652

Capacitors

C1	47n greencap

Semiconductors

D1-D7	1N4148, 1N914 etc
IC1	7402

Miscellaneous

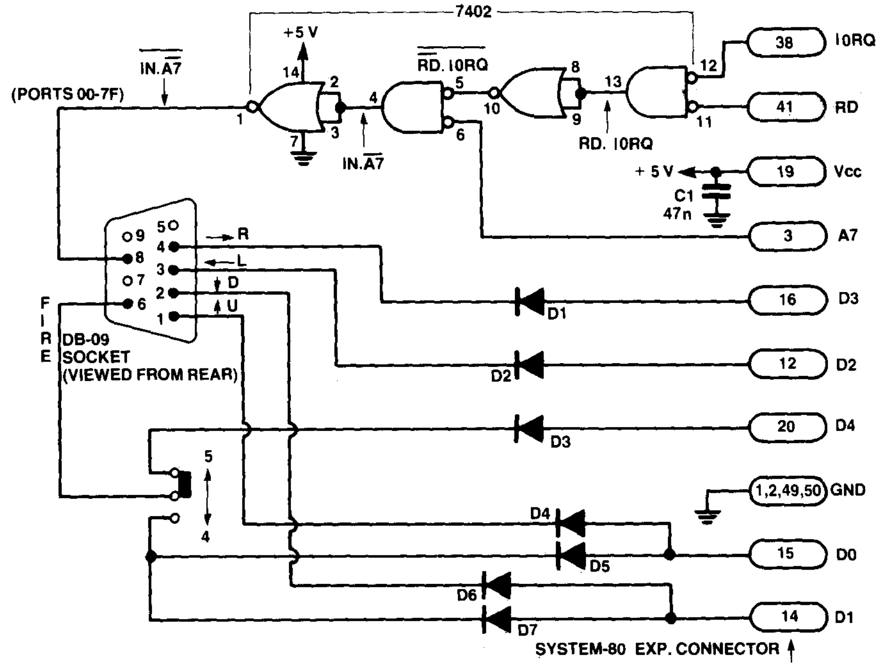
ETI-652 pc board; UB5 jiffy box (28 x 54 x 83 mm) or similar; 50-way edge connector socket; 300 mm length of 50-way ribbon cable; 9-way DB plug, chassis-mount, to suit joystick line socket connector; SPDT slider switch; nuts, bolts, glue etc.

Price estimate
$35 — $40
(includes joystick)

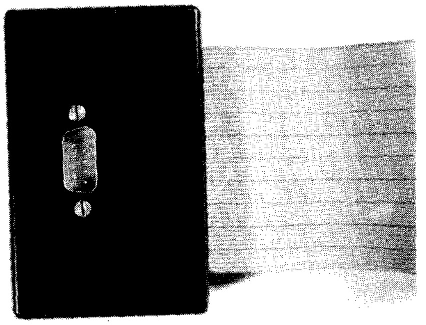
HOW IT WORKS — ETI-652

The joystick unit itself comprises four direction switches and a fire switch in a square, shallow case, operated by the stick which you grasp in your hand. A cable and 9-way plug provides connections. When a switch is activated, it connects one of the pins 1, 2, 3, 4 or 6 in the plug to the common line — pin 8. The five switches are encoded into either four or five data bits according to the position of switch S1. The five-bit mode connects each switch to a separate data line. The four-bit mode indicates the fire switch by activating the UP and DOWN line simultaneously, via diodes D5 and D7. The four-bit mode is provided to ensure compatibility with early joystick software.

The System 80 data buss is pulled high by internal resistors. The joystick therefore uses an active low to indicate a key closure. IC1, a quad NOR gate, decodes the control signals IORQ, RD and address buss bit 7 to make the interface appear to the computer as an I/O device occupying input ports 00 to 7F. This leaves 128 input ports free for other purposes. When the computer executes an INPut instruction within the range 00 to 7F, pin 1 of IC1 goes low and allows the data buss lines to be selectively pulled down via the joystick switches and the diodes, which prevent the buss from being affected when the joystick interface is not selected.



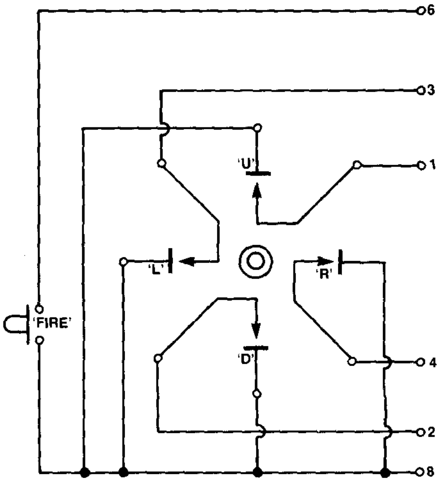
Circuit of the interface.



View of the completed interface. Note orientation of the 9-way DB plug and location of the slide switch.

Trying it out

This is only a matter of plugging the joystick into the interface, then the interface into the System 80 and testing it with some suitable software running. You can try a cassette program or key in the program listed here. Any problems encountered are almost certainly due to wiring errors. A re-check of your wiring and orientation of components on the pc board should throw some light on the problem. ●



Circuit of the joystick showing pin connections on the 9-way line socket.

JOYSTICK DEMONSTRATION PROGRAM

```
5    REM: POSITION CURSOR IN CENTRE
10   CLS: X=63 : Y=23
15   REM: READ AND INVERT JOYSTICK
20   A=255 - INP(0)
22   REM: SET POINT UNLESS FIRE BUTTON ON
25   SET(X,Y)
30   IF A>15 THEN RESET(X,Y) : A=A-16
35   REM: FLASH CURSOR ONCE , BUT LEAVE IT THE SAME
40   C=POINT(X,Y)
50   IF C=0 THEN SET(X,Y) : GOSUB300 : RESET(X,Y) : GOTO 70
60   RESET(X,Y) : GOSUB300 : SET(X,Y)
65   REM: THIS SECTION UPDATES CURSOR POSITION ACCORDING TO JOYSTICK
66   REM: DIRECTION. IF JOYSTICK IS IN CENTRE A=0 AND IT FALLS THROUGH
70   IF A>7 THEN X=X+1 : A=A-8
80   IF A>3  THEN  X=X-1 : A=A-4
90   IF A=2 THEN Y=Y+1
100  IF A=1 THEN Y=Y-1
105  REM : THIS SECTION WRAPS THE SCREEN AREA AROUND TO AVOID AN
106  REM : ERROR MESSAGE CAUSED BY AN OUT OF RANGE PLOT INSTRUCTION
110  IF X>127 THEN X=0
120  IF X<0 THEN X=127
130  IF Y>47 THEN Y=0
140  IF Y<0 THEN Y=47
145  REM: LOOP BACK TO START
150  GOTO 20
295  REM : DELAY ROUTINE FOR FLASHING CURSOR
300  FOR N=1 TO 20 : NEXT N : RETURN
```

This program puts up a flashing cursor in the middle of the screen. When you move the joystick the cursor 'writes' according to the direction in which you move the joystick shaft. You can move the cursor without writing by holding down the 'fire' button. Now try writing your name! Have fun with your joystick.

Project 161

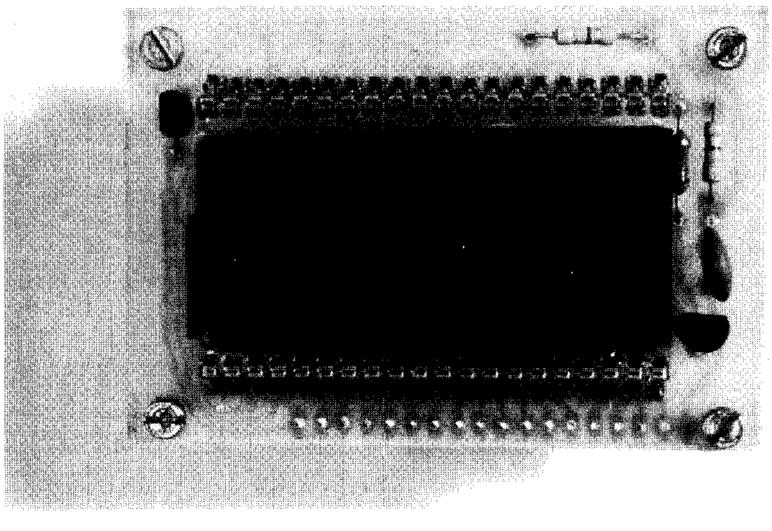
Versatile digital panel meter with liquid crystal display

David Tilbrook

This simple, versatile project can be used as the basis of many test instruments or as a stand-alone meter to measure voltage (as low as 200 mV) or current.

THERE ARE many applications that require a digital readout of dc voltage. To fulfil this requirement we published a digital voltmeter, the ETI-135 digital panel meter in October 1977. It was based around the Intersil ICL7106 digital voltmeter IC, which was at that time available in the form of an evaluation kit. Although the individual ICs are widely distributed now the evaluation kits are becoming scarce. For this reason we have decided to republish the design in a form suitable for commonly available components. The kit was supplied with small rectangular capacitors enabling them to be laid on their side to reduce height and allow the display to be mounted as closely as possible to the front panel. Unfortunately these capacitors are not commonly available. Greencaps work well in this application but their physical size requires a new pc board layout.

We overcame these problems by designing a pc board suitable to be cut in half. The display, the 7106 IC and a few other components mount on one of the pc boards, while all other components, including the battery if required, mount on the other pc board. This enables almost any sized components to be used and by mounting one of the pc boards behind the other, ensures the display occupies as little front panel space as possible. ▶



SPECIFICATIONS

Full scale readout	depends on setup. Full scale sensitivity is 199.9 mV
Resolution	100 uV
Accuracy	$<$ 1 digit when correctly calibrated
Display	3½-digit LCD
Input Impedance	$> 10^{12}$ ohms
Input bias current	approx. 2 pA
Polarity indication	automatic
Conversion method	dual slope
Reference	internally generated ±100 ppm
Power supply	9 V @ approx. 1 mA

Construction

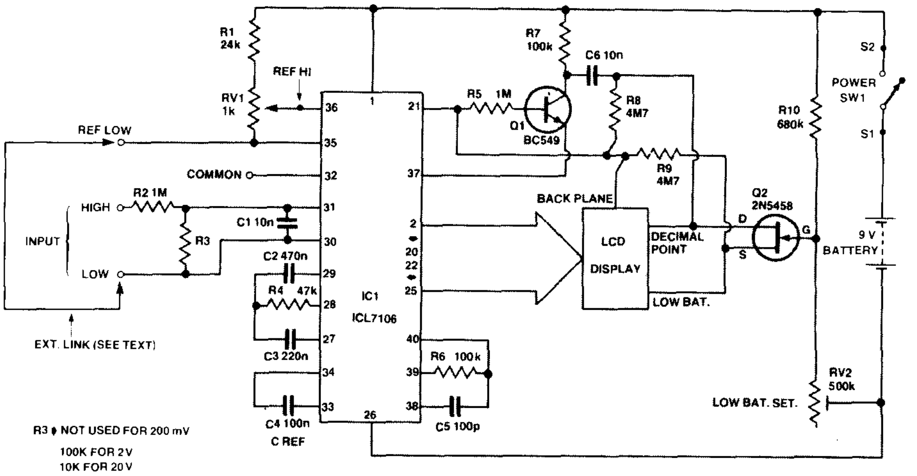
The project can be constructed in two forms, either on a single pc board, or as mentioned above, by cutting the pc board in half and mounting one half behind the other. If your application requires that the pc board be cut, do so before mounting any of the components.

Start construction by deciding on the sensitivity that best suits your requirements. This decides the value of resistor R3. If a 200 mV (199.9 mV) maximum sensitivity is required R3 is omitted. For a 2 V (1.999 V) meter, the required value of R3 is 100k while for a 20 V (19.99 V) meter, use 10k.

If the meter is setup for 200 mV operation it is advisable to solder an additional 1M resistor in parallel with the input, i.e: directly from the low input terminal to the high input terminal. This reduces the input impedance of the meter to 1M and reduces the sensitivity of the instrument to stray static voltages. Without this resistor the display has an input impedance of more than 10^{12} ohms. So the input capacitance can easily become charged by static, prohibiting the meter from zeroing correctly. On the other ranges, a parallel resistor is automatically present so the additional 1M resistor is not necessary.

Having decided on the value of R3, solder all resistors and capacitors onto the pc boards, with the exception of capacitor C6. Next, solder the 10-turn trimpot, RV1, and the 'low batt.' set trimpot, RV2. The latter is best mounted lying down. If the project is constructed using the single pc board approach all the capacitors should also be mounted lying down so that the display can be as close as possible to the front panel. If the twin pc board approach is used only those components mounted under the battery need be mounted lying down. The battery is mounted on a 9 V battery clip using 6 mm long spacers as shown in the accompanying photos. If the project is constructed using the single pc board approach, mount the battery clip, once again with 6 mm spacers, but on the copper side of the pc board.

The main IC and the liquid crystal display can now be mounted. The 7106 is mounted under the LCD display, so if a socket is required ensure that it is a low height type. Otherwise, solder the IC directly to the pc board making sure that the device has been inserted the right way around. Check this against the construction overlay before soldering. The LCD display should be mounted using Molex pins. This spaces the display off the pc board and ensures that the transistors and capacitors around the display are not higher than the display itself. It is probably easier to plug in the display before soldering the remaining components. There are no convenient orientation marks on the display so it is necessary to hold it at a slight angle and look for the outline of the digits. The display should be mounted with the decimal points at the bottom and the 'LOW BAT' indicator in the top left hand corner of the display.



PRINTED CIRCUIT ARTWORK for this project is on page 64.

Finally, solder the remaining transistors and capacitor C3, being careful to orientate the transistors correctly and not to scratch the front glass of the display.

If the single pc board approach has been adopted, construction is complete at this stage. If the twin pc board approach has been used however, it is necessary to solder the 18 wire links

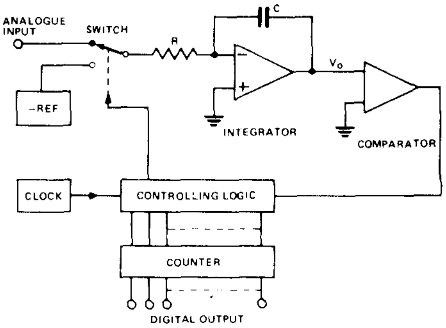
HOW IT WORKS — ETI-161

Most of the work is done by the ICL7106 IC. This uses the dual-slope integration technique to ensure good long-term accuracy and reliable operation. The analogue input is first converted to a time period which is then converted to a binary number by a digital counting system. This conversion system is illustrated in the block diagram. When the switch connects the analogue signal input to the input of the integrator, the output from the integrator ramps up at a rate determined by the input voltage. At the same time, the counter is started at zero and begins to count clock pulses. When a predetermined number of pulses has been counted the input is switched to the reference by the control logic. At this time, the integrator capacitor, C, has been charged linearly to some voltage determined by the input voltage. As the switch changes to the reference, the counter is reset to zero and commences counting again. The reference is of appropriate polarity to that of the input signal and so causes the integrator to ramp down with a fixed slope. When the output reaches zero, the counter is stopped and its contents displayed on the digital readout. The count displayed is the ratio of the counts during the downward ramp to the counts during the upward ramp.

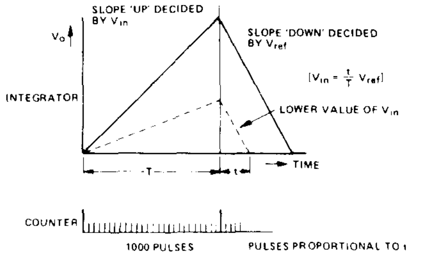
The value of the integrator capacitor and clock frequency are of little significance, provided they are stable for the duration of the conversion period.

This is a true dual polarity system so the integration direction depends on the polarity of the input voltage. Provided ac ripple on the input averages to zero over the count time it will be rejected. If 50 Hz ripple is to be rejected, for example, a 50 kHz clock rate could be used, giving an 80 ms sampling time (four cycles of 50 Hz). The clock can be adjusted by varying the value of R6. We experienced no problem with 50 Hz ripple. Capacitor C1 in conjunction with resistor R2 function as a low pass filter with a −3 dB rolloff point well below 50 Hz.

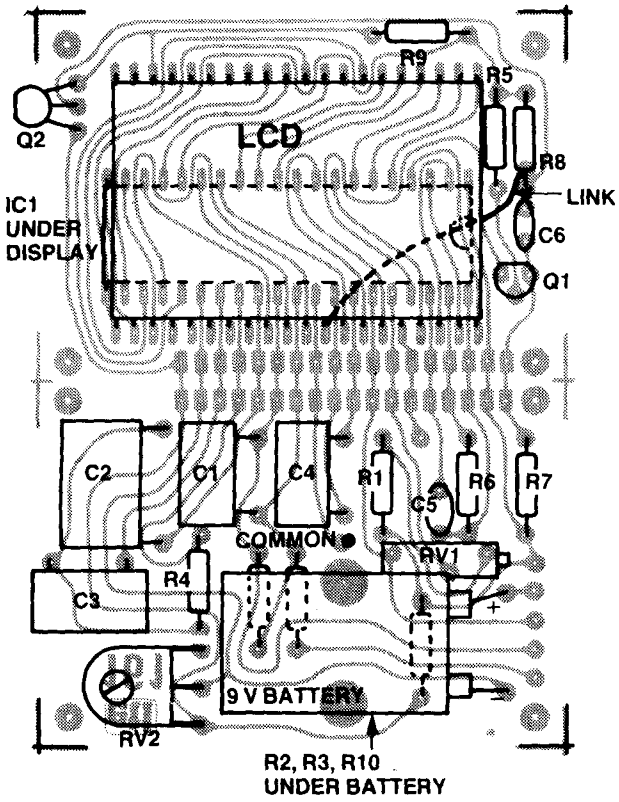
The 2N5458 JFET (Q2) is used simply as a voltage sensor to monitor the battery voltage and drive the LOW BAT indicator if the voltage falls below that determined during set up.



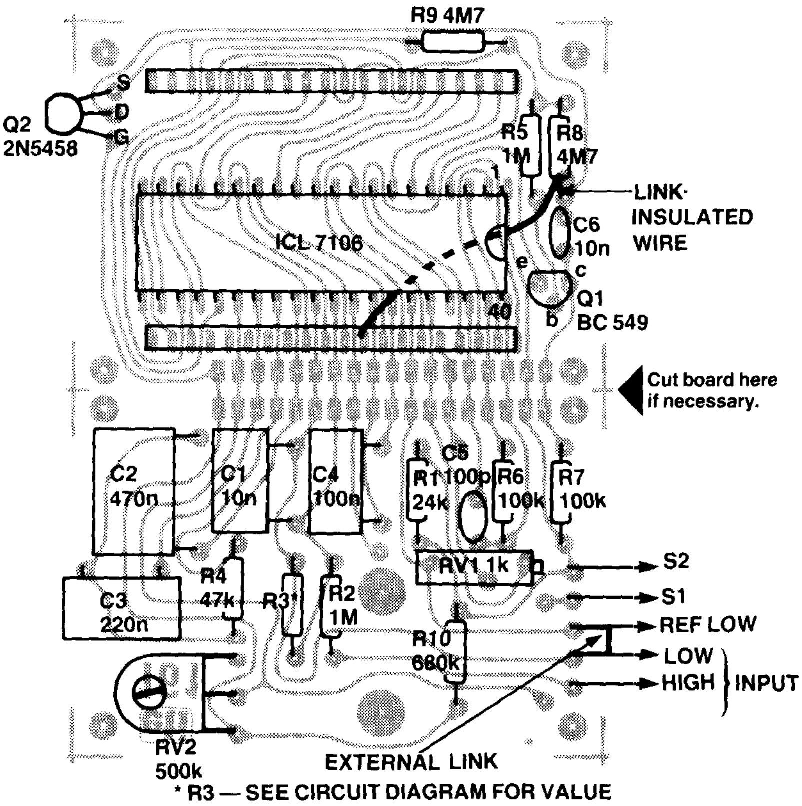
Block diagram of the dual-slope integration technique



Timing diagram of the dual-slope A/D conversion technique.



COMPONENT OVERLAY SHOWING POSITION OF LCD AND BATTERY



COMPONENT OVERLAY WITHOUT LCD OR BATTERY SHOWING POSITION OF IC, R2, R3 AND R10

between the two boards. Before doing this however, solder a lead from the point on the pc board marked 'COM.' It is necessary to connect this point to one of the two input terminals. The usual method is to connect COM to the low input. Also, connect REF LOW to the low input. This configures the meter to a normal absolute reading voltmeter that will display the voltage between the low and high input terminals with normal polarity indication. The module is also capable of ratiometric measurement. For information about this application consult the data sheet included for the ICL7106.

Mount the pc boards, spacing them approximately 20 mm apart, either using spacers or simply an entire set of nuts on the four mounting bolts. Use tinned copper wire to make the links between the pc boards, soldering each one at both ends before proceeding to the next. A fine-tipped soldering iron and fine solder (22g) should be used for this project and is especially important at this stage.

Calibration

Before powering up, ensure that all components have been soldered correctly and have been inserted with the correct orientation. If all is well plug in the battery and connect the points S1 and S2 to each other. The display should immediately stabilise with all digits reading zero. Use a power supply to generate a test voltage and adjust RV1 so that the panel meter agrees with another voltmeter. Preferably use a digital voltmeter for this, although a good analogue instrument can also be used with decreased accuracy. RV2 is used to adjust the low battery indication on the display. The best way to do this is to run the unit from an adjustable power supply, checking operation against a known voltmeter while decreasing the supply voltage. Set the LOW BAT indicator to come on at a supply voltage just above where the panel meter fails to read accurately. Do not exceed 9 V on the supply leads when doing this test.

Once calibrated correctly this project is capable of very accurate measurement. The 7106 is used in many commercial digital multimeters and the high input impedance enables the module to be used in many applications.

We intend publishing several projects using the display, but even as a general purpose dc voltmeter the module has proved very useful. A 1R shunt resistor can be soldered directly across the input to convert the module into a dc current meter reading in milliamps (i.e: 199.9 mA). Use an 0R1 shunt to read dc amps (i.e: 1.999 A). Add an 'absolute value' generator to enable ac voltage or current to be measured. ▶

PARTS LIST — ETI-161

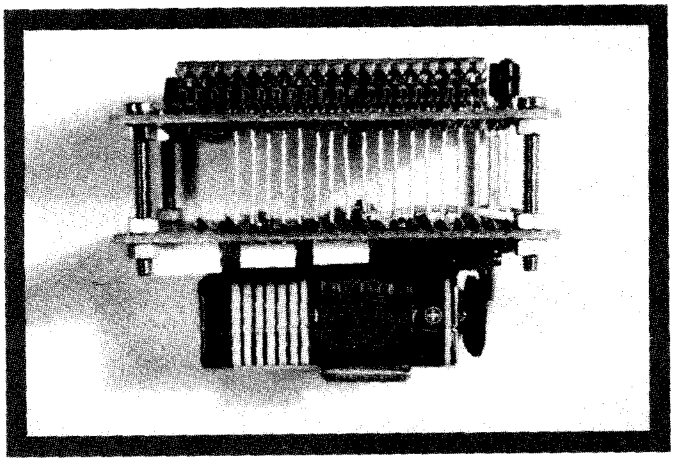
Resistors	all ¼W, 5%
R1	24k
R2, R5	1M
R3	see note
R4	47k
R6, R7	100k
R8, R9	4M7
R10	680k
RV1	1k 10-turn trimpot
RV2	500k horizontal trimpot
Capacitors	
C1	10n mylar, 50 V
C2	470n mylar, 50 V
C3	220n mylar, 50 V
C4	100n mylar, 50 V
C5	100p NPO ceramic
C6	10n ceramic
Semiconductors	
IC1	ICL7106
Q1	BC549, BC109
Q2	2N5458, MPF106

Miscellaneous

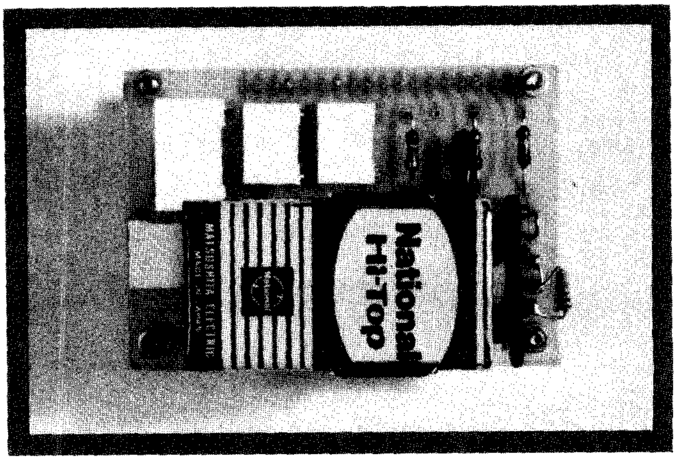
ETI-161 pc board; LAD204 liquid crystal display (from Intersil evaluation kit) or similar; battery holder clip for No. 216 battery (if required); SW1 — SPST switch (if required); two 6 mm long spacers; four 20 mm spacers (if required); nuts and bolts to suit assembly; No. 216 9 V battery (if required).

Price estimate **$30 — $35**

NOTE: many of these components are available in the Intersil Evaluation kit, particularly the 7106, the display and the capacitors.



View of the panel meter with the 'electronics' board mounted behind the 'display' board, showing the connections run between the two boards and how the battery is mounted.



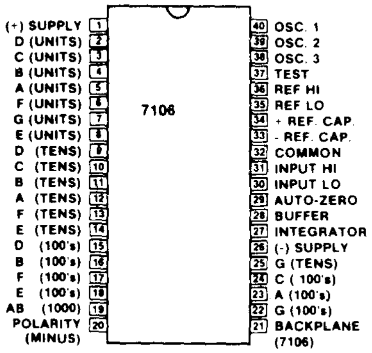
Rear view of the 'electronics' board showing battery positioning. If an external supply is used the battery and battery mounting components can be dispensed with.

ICL7106
3½ Digit Single Chip A/D Converter

FEATURES

- Guaranteed zero reading for 0 volts input on all scales.
- True polarity at zero for precise null detection.
- 1 pA input current typical.
- True differential input and reference.
- Direct display drive - no external components required. — LCD ICL7106
  — LED ICL7107
- Low noise - less than 15μV pk-pk.
- On-chip clock and reference.
- Low power dissipation - typically less than 10mW.

PIN CONFIGURATION



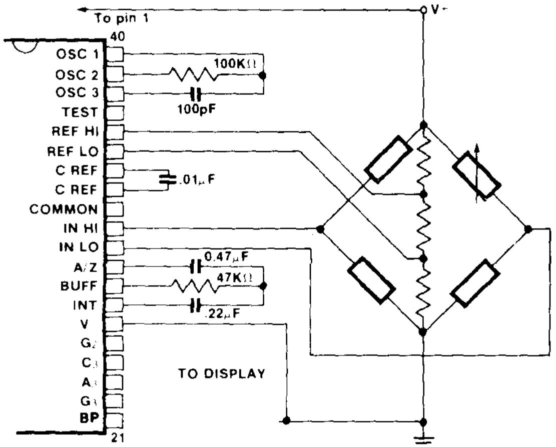
ABSOLUTE MAXIMUM RATINGS

ICL 7106

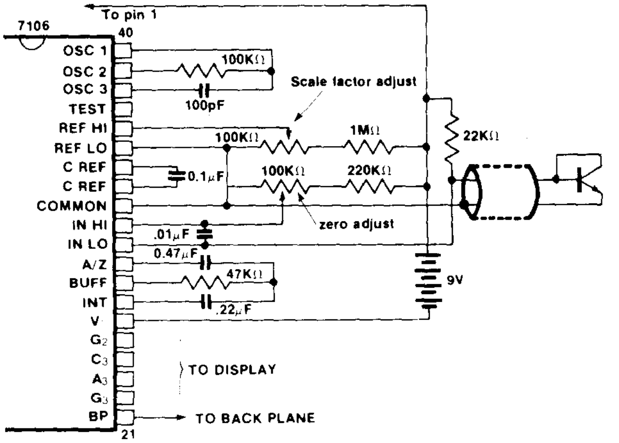
Supply Voltage (V+ to V-)	15V
Analog Input Voltage (either input) (Note 1)	V+ to V-
Reference Input Voltage (either input)	V+ to V-
Clock Input	Test to V+
Power Dissipation (Note 2)	
Ceramic Package	1000 mW
Plastic Package	800 mW
Operating Temperature	0° C to +70° C
Storage Temperature	-65° C to +160° C
Lead Temperature (Soldering, 60 sec)	300° C

Note 1: Input voltages may exceed the supply voltages provided the input current is limited to ±100μA

Note 2: Dissipation rating assumes device is mounted with all leads soldered to printed circuit board.

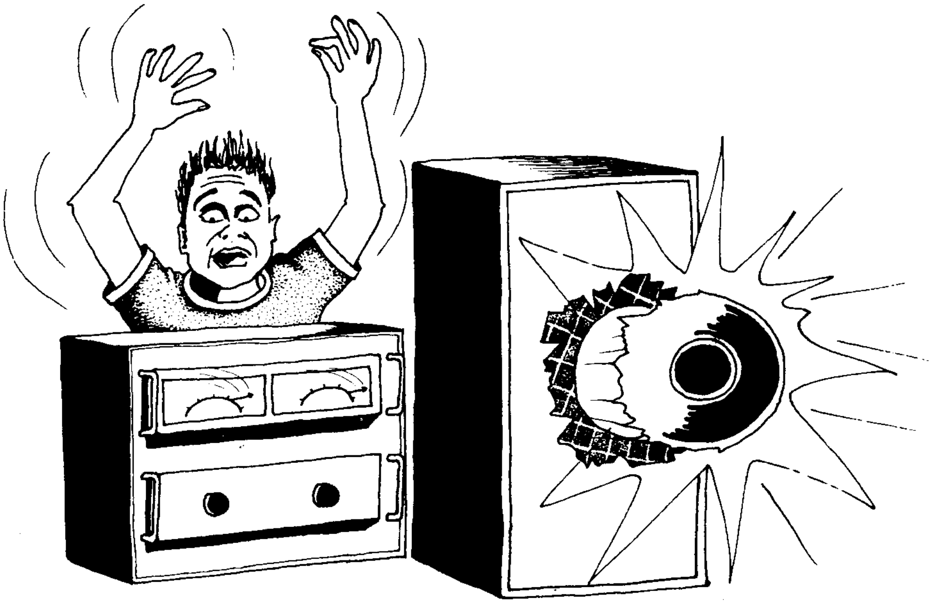


7106 measuring ratiometric values of Quad Load Cell. The resistor values within the bridge are determined by the desired sensitivity.



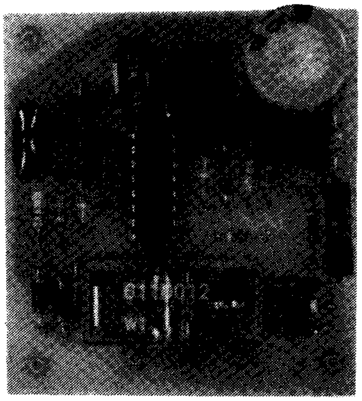
7106 used as a digital centigrade thermometer. A silicon diode-connected transistor has a temperature coefficient of about -2mV/° C. Calibration is achieved by placing the sensing transistor in ice water and adjusting the zeroing potentiometer for a 000.0 reading. The sensor should then be placed in boiling water and the scale-factor potentiometer adjusted for 100.0 reading. ●

Project 494



Signal powered loudspeaker protector

David Tilbrook



This unit affords both dc and over-power protection of loudspeakers or loudspeaker systems rated at up to 1500 watts! The unit requires no power supply and has no discernible audible effect on sound quality making it suitable for both hi-fi and sound reinforcement applications.

THE ETI-455 loudspeaker protector has proved to be a very popular project. It was published in March 1980 and since then we have had numerous phone calls from readers with stories of how the unit had saved their loudspeakers from almost certain disaster. Usually the power amplifier had gone faulty and applied the full dc supply rail to the loudspeaker terminals. Without the loudspeaker protector in circuit the result would be at least an open circuit bass driver and probably worse. The protector prevents this by monitoring the loudspeaker lines for the presence of dc, opening a set of relay contacts if this occurs, disconnecting the loudspeaker from the faulty amplifier.

The ETI-455 works well but requires its own power supply, either batteries or a small regulated mains supply. Another disadvantage results from the type of filter used to distinguish between dc and the audio signal. This was a conventional passive filter set to around 10 Hz. The problem is that it is still possible with very large amplifiers to trigger the protector on low frequency audio content. So the circuit, although perfectly satisfactory for its quoted maximum power of around 100 watts or so, is unsuitable for very high powered amplifiers.

We decided to overcome these limitations in this new loudspeaker protector, the ETI-494. Since the old one was published we have had numerous requests for a circuit that could be mounted inside a loudspeaker enclosure. These requests have come largely from the sound reinforcement industry although the unit would obviously be applicable to all loudspeakers. The protector would not be able to be powered from a mains supply since it is not always desirable or even possible to run mains to the loudspeakers. This is particularly true in a sound reinforcement or public address system. Similarly, batteries are unsuitable since access would have to be provided to facilitate testing and changing them when required. In addition, when we first published the ETI-499 MOSFET PA Module (ETI March 1982), we promised to follow up with a loudspeaker protector. This is it. The solution, used in this project, is to power the unit from the audio signal itself.

This is done in this case by placing a fullwave rectifier across the speaker lines and charging a 1000u capacitor through a 47 ohm resistor. The worst possible load presented to the speaker line is therefore 47 ohms and this is only while charging the capacitor and for signal voltages in excess of 12 V. This ensures that the unit has no discernible effect on audio quality but makes ▶

possible a truly 'set-and-forget' loudspeaker protector that can be mounted inside the loudspeaker enclosure if desired.

The ETI-494 tests for both dc and over-power, which can be adjusted by a preset on the board to suit a particular loudspeaker or application. The circuit also uses a new filter design with an almost 'brick wall' response enabling it to be connected to very high power amps. This is discussed in more detail in the 'How it Works' section.

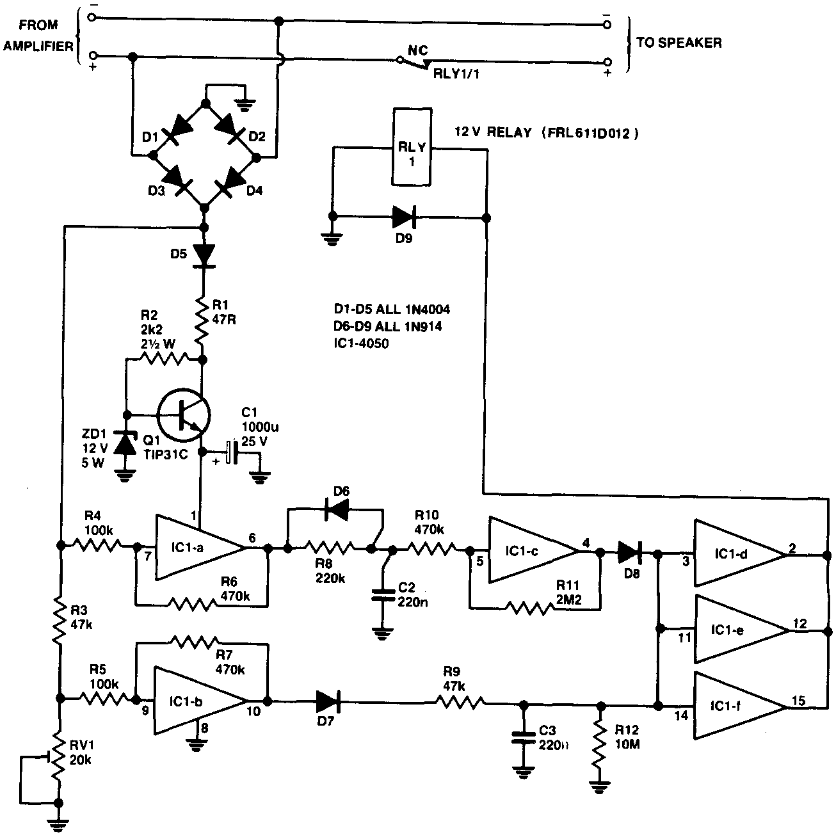
The maximum power that can be applied to the unit is determined by the type of regulator transistor (Q1) used. We have specified a TIP31C for this device which has a 100 V collector-to-emitter breakdown voltage. Since the emitter is at 12 V, the maximum voltage that can be applied to the unit is 112 V. This is equivalent to an amp capable of

HOW IT WORKS — ETI 494

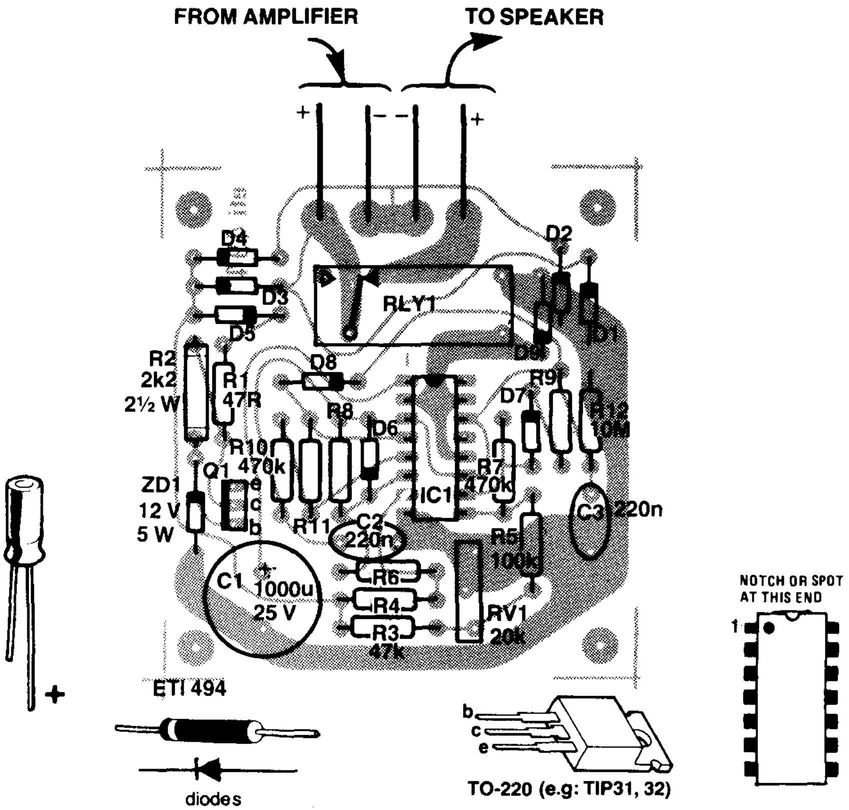
The signal from the power amp is rectified by the fullwave rectifier formed by D1-D4. The output of this is fed through a 12 V regulator circuit formed by Q1 and its associated resistors and zener diode, and charges the electrolytic capacitor, C1. The output of the rectifier is also fed to the input of the dc sense and over-power detection circuitry.

IC1 gates a and c form the dc filter. Resistors R4 and R6 form a Schmitt trigger with a small deadband. When the signal goes above the trigger voltage the output of the trigger swings hard to the positive supply rail of the IC, charging C2 through the 220k resistor, R8. Resistors R10 and R11 with gate c form a second Schmitt trigger monitoring the voltage across C2. If the voltage across C2 reaches the trigger voltage of this second Schmitt, gates d, e and f are activated, pulling in the relay contacts and disconnecting the loudspeaker. It takes about 100 ms to charge C2 through R8, and on normal audio content the output of gate 'a' will be driven low before this occurs, discharging C2 rapidly through D6. Only signals which do not have a zero crossing for longer than 100 ms will trigger the protector.

The over-power protector consists simply of a voltage divider feeding a third Schmitt trigger. Whenever the signal voltage exceeds the trigger voltage the output of gate 'b' is driven high and C3 starts to charge. If this condition persists for long enough the output gates are turned on and the relay pulls in. Note that both the dc and over-power sense circuits charge C3 when activated. The circuits are decoupled from this capacitor by diodes so that, once charged, C3 can only be discharged by the parallel resistor R12 (the effect of the input impedance of the gates is negligible). Since it takes about one second to discharge this capacitor, the relay will hold in for this time. The protector therefore reconnects the loudspeaker approximately one second after the fault condition has been removed.



The pcb pattern is on page 64.



PARTS LIST — ETI-494

Resistors	all ½ W, 5% unless noted
R1	47R
R2	2k2, 2½ W
R3, R9	47k
R4, R5	100k
R6, 7, 10	470k
R8	220k
R11	2M2
R12	10M
RV1	20k min. trimpot
Capacitors	
C1	1000u/25 V RB electro.
C2, C3	220n greencap
Semiconductors	
D1-D5	1N4004, EM404
D6-D9	1N914, 1N4148
IC1	4050
Q1	TIP31C
ZD1	12 V, 5 W zener

Miscellaneous

ETI-494 pc board; RL1 — Fjuitsu FRL611D012, 12 volt SPDT 10 A contacts or similar relay (pc mount type).

Price Estimate
$20-$24

supplying approximately 784 watts into an 8 ohm load or 1568 watts into a 4 ohm load. If the amplifier to be used is capable of powers greater than these the regulator transistor should be substituted for a device with a higher V_{ceo} rating. The relay pulls around 40 mA when operated, so power dissipation in the regulator transistor will be around 4 watts when dropping 100 volts. Although this is not a particularly high dissipation it is high enough to lie outside the SOAR rating of many high voltage transistors, so be careful when choosing an alternate regulator transistor.

Construction

Construction is straightforward since all of the components are mounted on the pc board. The usual precautions should be taken to ensure that all polarised components have been mounted with the correct orientation. The IC used is a CMOS type and is therefore static sensitive. Solder this last and preferably using an earthed soldering iron. It is a wise precaution to discharge yourself before handling the device by first touching an earthed metal appliance. For a more detailed description of precautions when handling CMOS refer to our article 'Electrostatic discharge — nemesis of electronic systems' in the June edition, 1981.

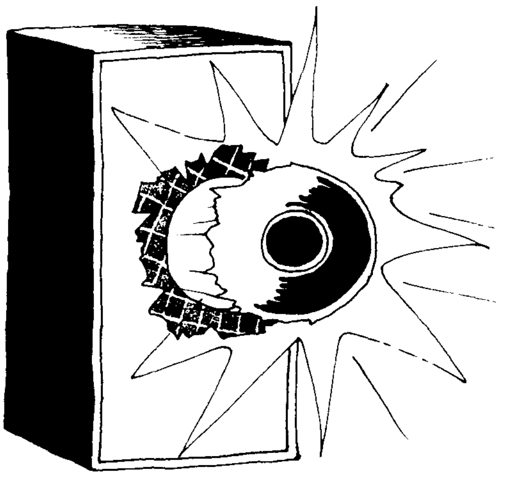
It is a wise precaution to space the 2.5 W resistor, R2, off the pc board slightly. In the case of a high powered loudspeaker going faulty with dc this component will get quite hot and spacing improves ventilation around the component and prevents the possibility of charring the pc board. If you can't obtain a 2.5 watt type (e.g. Philips PR52), then a 5 W type may be substituted.

Before mounting the unit check operation by connecting around 20 V dc across the speaker input terminals on the pc board. The relay should cut in after about one tenth of a second. If the protector passes this test connect the speaker wiring. If the preset is turned fully down (turn it anticlockwise when viewing the board with the components on top and the relay to the right) the relay will cut in when the power exceeds around 20 watts for an extended period. The protector allows transients to the full supply rail to pass but will prevent a continuous 20 W from being applied to the loudspeaker. To increase this, turn the preset clockwise until the desired response is achieved.

Performance

We tested the loudspeaker protector for its effect on audio performance as well as its reliability. A variety of power amps were used to ensure that the load represented by the protector would not affect audio performance. Even a very low power amplifier, with a comparatively small damping factor (high output impedance) could drive the unit with no degradation to the sound quality. During every test the protector worked well and cut in at the correct time to prevent damage to the loudspeakers.

NOTE. *Some amplifiers are unstable when driven into an open circuit. This is particularly true of valve power amplifiers some of which destroy themselves the moment the speaker is disconnected. Loudspeaker protectors are however, not usually r quired for use with valve power amps since the possibility of dc on the speaker lines is remote, but over-power protection may be required.* ●



OPERATING NOTES — PROJECT 494

A loudspeaker protector such as this is basically meant for a *once-only* operation. It is not meant for successive cut-in, drop-out operation, particularly in the case of a dc fault. This project should not be used if you're trying to trace an intermittent dc fault. If the relay operates, it's time to switch off the amplifier, disconnect the load and find the fault — preferably using a dummy load. For amplifiers having supply rails in excess of about 50 V, it is advisable to add dc-quenching across the relay contacts. A series RC network is all that's necessary. Use a 100 ohm, 1 W resistor and a 630 V rated capacitor of about 100 n or greater value.

For really high power amplifiers having supply rails of 100 V or more, it is probably best to use two relays with their coils connected in parallel and their contacts (with de-quenching) connected in series.

Project 1509

Universal dc-dc inverter

This inverter can be configured to suit a wide variety of applications — powering our audio amplifier modules from a 12 V battery, powering 12 V equipment from a 24 V or 32 V battery, deriving a high voltage supply from a low voltage dc source etc, etc.

David Tilbrook
Roger Harrison

WE'VE CALLED this a 'universal' dc-dc inverter as it has been designed so that, simply by winding the appropriate secondary, or secondaries, on the output transformer you can derive almost any dc output voltage(s) you want. Thus, this project can be used to power any of our audio power amplifier modules (ETI-470, ETI-477, ETI-480, ETI-499), with perhaps the exception of the ETI-466 300 W amp. You can power the ETI-565 HeNe laser and the ETI-452 Guitar Practice Amp, or any other project or device you desire, providing it falls within the power rating of the inverter.

We described a dc-dc inverter power supply to power a PA/guitar amp employing one of our 100 W '480 modules way back in May 1977. This was the ETI-481PS which provided ±40 V rails from a 12 V battery. It ran at 20 kHz and required special rectifier diodes, a pot-core and a ferrite transformer assembly — all of which are now very difficult, if not impossible, to obtain. Since we described the Series 5000 stereo power amplifier in the January-February-March '81 issues of ETI, many readers have sought to adapt it for use in their vehicles (car/truck/sin bin . . .). Parts for the ETI-481PS have now virtually 'dried up' and we have been pressed to do a 'replacement'. Well, this is it, albeit with some refinements.

We decided to make this inverter a 'universal' project as it struck us there are wider applications than was first envisaged. Besides, we've had a number of requests for a 12 V inverter to power the ETI-565 HeNe laser, both to provide portability and to free it from mains operation for improved safety. It seems that many schools have built the laser for use in their science labs.

Design considerations

A number of factors were considered of prime importance when we tackled the design of this inverter. First came the frequency of oscillation. Would we have a low frequency design, which eases component selection and ensures their availability, or set the oscillation frequency above the audio band? A third option was to do something between those two extremes. Cost, size and component availability were also important.

The problem with a low frequency inverter, operating at — say — 2 kHz or less, is suppressing the switching 'spikes' that appear on the power supply rails. This can be difficult and these spikes almost inevitably create interference in low-level input stages. As the spikes contain predominantly odd harmonics the result is a cacophony of buzzes that is constantly present. Rectifier filter capacitors at the lower frequencies are, by necessity, large and we didn't want a bulky project.

Setting the inverter oscillation frequency above the audio band, at 20 kHz for example, gets rid of the above problem but introduces several others. Circuit techniques that work at low frequencies require specialised components at 20 kHz. Hence, a different inverter technique is necessary, and this inevitably increases costs and specialised components often prove hard to get — which became the major problem with the ETI-481PS which ran at about 25 kHz.

We chose the median course. Setting the oscillation frequency at around 6-7 kHz puts the odd harmonics where they (mostly) won't be heard. Filtering is easy and suitable capacitors are compact.

We wanted a design that used a minimum number of components, so that the project would be compact, but consistent with the other restraints. There are three common techniques employed in transistor dc-dc inverters these days — the self-excited single transformer circuit, the self-excited dual transformer circuit and the driver inverter.

The self-excited single transformer inverter is by far the simplest. The general form of this inverter is shown in Figure 1. The transistors operate in push-pull and feedback is taken from a winding on the output transformer. It has two great advantages — simplicity and high efficiency. With proper choice of transistors, efficiency can be in excess of 90%. However, at the sort of powers

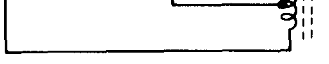


Figure 1. **Typical circuit of a self-excited single transformer dc-dc inverter. Efficiency of this type of circuit often exceeds 90%, with correct choice of transistors.**

we envisaged the inverter would have to deliver — around 200 W or so — switching transistors with suitable current ratings and low saturation voltages (for that's where you lose efficiency) are not cheap, or readily available. Germanium switching transistors are the best. Tried to buy a 20 A germanium switching transistor lately? Some MOS switching devices are also suitable, but still hard to get. You could parallel transistors of lower current rating but the traditional method of using emitter 'ballast' resistors severely affects efficiency. By using a special primary winding on the transformer, as shown in Figure 2, the devices are essentially in parallel but collector-emitter current sharing is done in the transformer primary. Base current sharing is effected by the series base resistors.

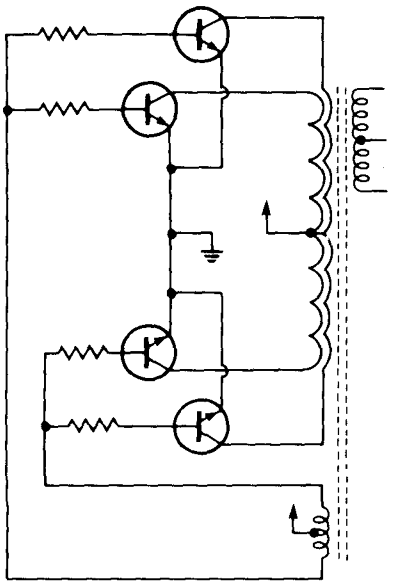


Figure 2. **Obtaining more power output from the simple self-excited inverter by means of 'paralleling' transistors with a special, quadrifilar-wound, primary. For high power use, lower cost transistors can be used.**

Thus, common-or-garden transistors, like 2N3055s, can be used and little power is lost here. The major drawback is attaining the required oscillation frequency. For this sort of inverter, the oscillation frequency is given by:

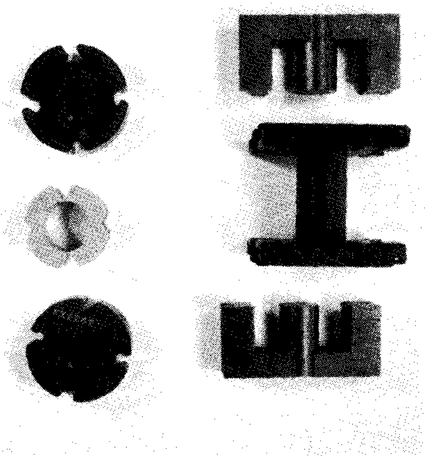
$$f \cong \frac{V_{supply}}{4N\delta_m}$$

where: f is frequency of oscillation
V_{supply} is dc input
N is primary turns, collector to centre tap
δ_m is magnetic properties of transformer core

Thus, for a given voltage and core properties, N must be relatively small to achieve the required frequency of oscillation. But here comes a catch. The feedback winding must develop enough voltage to drive the base such that the transistor(s) saturate properly. In practise, this means about 3 V. If the dc input is 12 V, you need a turns ratio of 4:1 between the primary and feedback windings. If you make the feedback winding (centre tap to one set of bases) one turn, then the primary has to be four turns. With available cores, the oscillation frequency did not even approach what we wanted.

A driven inverter is more complex, but it overcomes the problem just outlined. A typical arrangement is shown in Figure 3. This employs a low power, self-excited push-pull oscillator driving a set of push-pull output transistor switches which drive the output transformer. The old ETI-481PS inverter was of this type. Efficiency is the greatest drawback of this type of circuit. The driving oscillator always draws significant power. You can achieve efficiencies of 80%, typically, but at 200 W output, you're losing 40 W and in a battery system, this is not good.

We settled on the self-excited dual transformer technique, illustrated in Figure 4. Here, a separate feedback transformer is used and it is this which controls the frequency of oscillation. This enables the choice of the right sort of core to obtain realistic turns ratios and the desired frequency of oscillation. We managed to use a common potcore for the feedback transformer (a 36 mm diameter FX2242 type) and an EC-core for the output transformer of a type we have used previously (in the ETI-1505 fluorescent light inverter). Supply rail filtering can be done quite effectively with common greencaps. Ordinary 2N3055 transistors — which cost less than a dollar these days — can be employed, thus keeping the cost down. ▶



The transformer assemblies we used. At left is the FX2242 potcore assembly; right is the Philips EC52/24/12 assembly. Note the ferrite 'Es' of this assembly have round centre legs. The bobbins are shown in the middle.

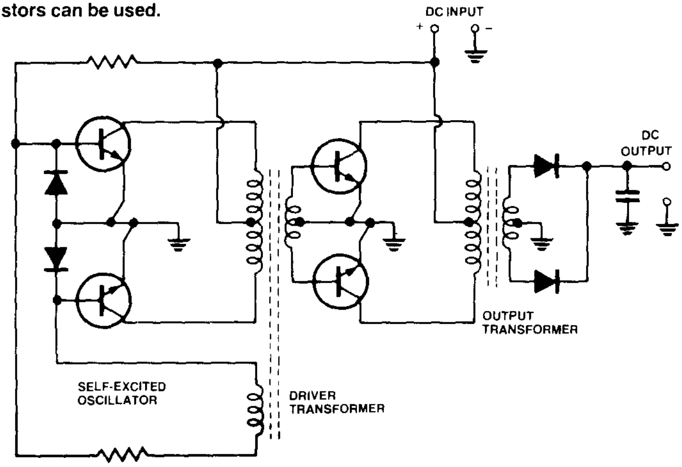


Figure 3. **Typical circuit of a driven dc-dc inverter where a low power self-excited oscillator drives a set of transistor switches which drive the output transformer. Of the three types, this technique has the poorest efficiency.**

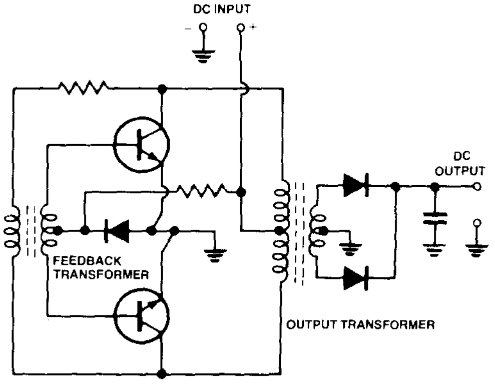


Figure 4. **Circuit of a self-excited dual transformer dc-dc inverter where the feedback is separated from the output transformer. In this circuit, the oscillation frequency is determined by the feedback transformer. Efficiencies similar to the Figure 1 circuit can be achieved.**

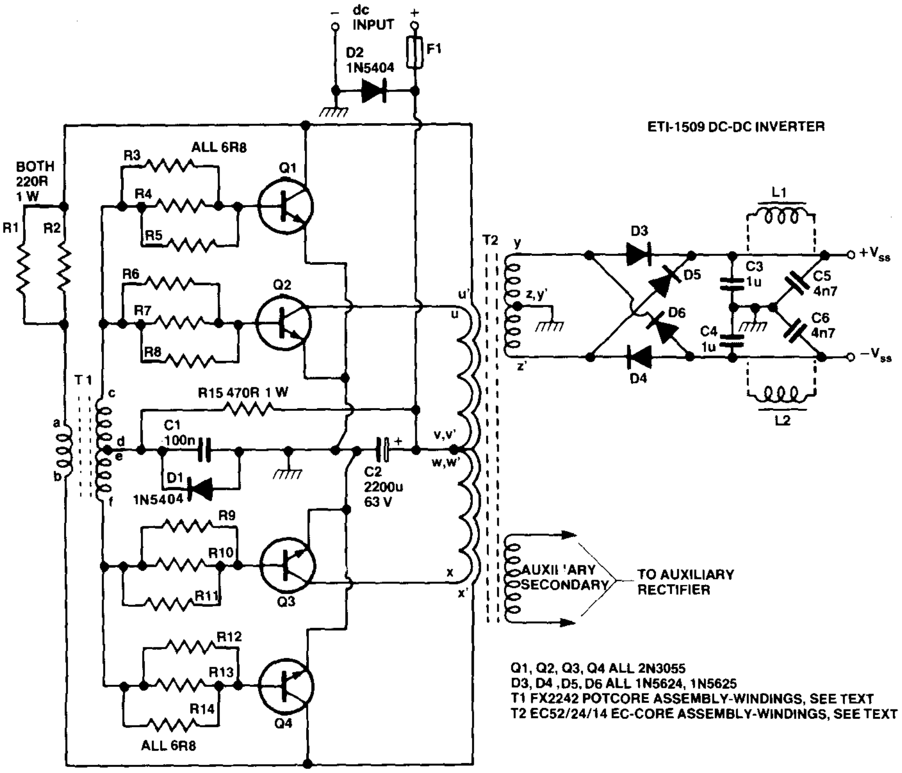


Figure 5. **Circuit of the universal dc-dc inverter. The two inductors shown at the rectifier output, L1 and L2, are only necessary if extra filtering of the dc output is necessary. These can be any value between about 1 mH and 10 mH. Speaker crossover inductors are ideal for this application. Choose inductors rated to carry the dc output current. At low currents (200 mA or less, say) RF chokes will suffice.**

HOW IT WORKS — ETI-1509

The circuit is a push-pull self-oscillating inverter with feedback provided by transformer T1, output being taken from T2. The moment the supply voltage is connected, current flows through the 470 ohm resistor R15, through the secondary of T1 (c-d-e-f) and the base current limiting resistors of the transistors Q1 to Q4. One of these transistors will turn on as circuit balance is not perfect and device characteristics are not matched. If, for example, Q1 commences to turn on, current will flow through the u'-v' primary of T2. This causes a magnetic field to build up in the transformer core creating a positive voltage on x' (x goes positive too). This puts a positive voltage on b of T1's primary which is wound and connected so that a positive voltage here causes a positive voltage on c of the secondary. Thus, the bases of Q1 and Q2 are driven positive, turning them hard on and the bases of Q3 and Q4 are driven negative, turning them hard off.

Since the primary of T1 acts as an inductor, the current flowing in it increases linearly for as long as the voltage is applied until finally the magnetic field intensity reaches a maximum, where the transformer core saturates. At this moment, the impedance of the core drops since the saturated core cannot maintain the relatively high inductance of the primary. The decreased impedance causes an increase in current flowing in the primary, driving the core even further into saturation until most of the coupling between the primary and secondary is lost. This causes the drive voltage to the bases to disappear. Current stops flowing in the transformer and the magnetic field starts to collapse. This causes the voltage sense of each winding to reverse. Thus, u and u' on T2 go positive and x-x' go negative. This causes b on T1 to go negative and thus c goes negative, removing charge from the bases of Q1 and Q2 which turn off. At the same time, f goes positive, turning Q3 and Q4 on. The whole sequence of events then repeats for the opposite 'side' of the oscillator, until once again, Q1 and Q2 are driven on and oscillation results.

The frequency of oscillation depends primarily on the core material of T1, the turns on its primary winding (a-b) and the applied voltage. In this case the frequency is around 6 - 7 kHz. Resistors R1 and R2 provide control of the feedback and diode D1 provides a return path for the base emitter current to the transistors when the secondary voltage of T1 reverses direction.

The output transformer, T2 has been arranged to provide a simple volt/turn ratio. Common, low cost 2N3055 transistors have been used and the special, quadrifilar-wound, primary is a means of effectively connecting pairs in parallel, as discussed in the main text.

Although a full wave bridge rectifier is shown here, any rectifier circuit may be used on the output. Filtering is readily provided by low value non-polarised capacitors, such as greencaps.

This inverter circuit, like the simple self-excited inverter shown in Figure 1, has the advantage that, when an overload or short circuit is applied to the output, oscillation cannot be maintained and it stops, which is not the case with a driven inverter. Thus, some protection is afforded both the inverter and the equipment connected to it.

Diode D2 prevents damage by blowing the fuse should the dc supply input be connected in reverse.

The circuit of the inverter is shown in Figure 5.

As it was to be a 'universal' inverter, the output transformer was designed to provide a simple volts/turn ratio for the secondary, making it easy to calculate and wind the secondary for the required output. The ratio is two volts per turn. A 'Table of Suggested Outputs' has been drawn up for a variety of applications. Note that more than one secondary can be wound on the output transformer if required.

Construction

The inverter can be housed in any convenient enclosure and we have shown only general construction as layout is not particularly critical. A suggested layout is shown in the wiring diagram. A metal case is assumed. Four tagstrips are used as tiepoints to terminate the two transformers and to mount the resistors, capacitors and diodes. The four transistors can be mounted to the case. No heatsink is necessary as little power is dissipated, but the transistor cases need to be insulated so use insulating washers and bushes as shown in the accompanying assembly diagram.

The primary windings of T1 are terminated to a 7-lug tagstrip. The collector of each transistor is connected to the appropriate lug on the tagstrip using heavy duty insulated hookup wire, preferably 32 x 0.2 mm or heavier, as switching currents can be in excess of 20 amps. The mounting lug of the 7-lug tagstrip is used as a ground tiepoint for the transistor emitters. Connect them up with heavy duty hookup wire too. Capacitor C2, the input protection diode D2 and the bias resistor R15 also mount on this tagstrip.

Two 5-lug tagstrips are used to terminate the feedback transformer, T1, and to support the base current limiting resistors and several other components.

The rectifier components are mounted on another tagstrip. The high frequency bypassing components should be mounted on a tagstrip away from the rectifier and very close to the hole where the supply output wires exit from the case. If extra filtering is necessary (by the addition of L1 and L2) then it is easily inserted between the rectifier tagstrip and the 3-lug tagstrip containing C5 and C6.

When laying out the components to suit your case, keep the two 5-lug tagstrips fairly close to the four transistors so that the base current limiting resistors can be easily mounted between the tagstrips and the base pins of the transistors. Also, mount the 7-lug tagstrip that terminates the primaries of T1, close to the transistors so that high

PARTS LIST — ETI-1509

Resistors	all ½ W, 5% unless noted
R1, R2	220R, 1 W
R3 — R14	6R8
R15	470R
Capacitors	
C1	100n greencap
C2	2200u/63 V axial electro. (or 2500u/50 V)
C3, C4	1u greencap
C5, C6	4n7 ceramic
Semiconductors	
D1, D2	1N5404
D3, 4, 5, 6	1N5624, 1N5625
Q1, 2, 3, 4	2N3055
Miscellaneous	
T1	FX2242 potcore assembly (windings, see text).
T2	Philips EC-core assembly (windings, see text). 2 x EC52/24/14 cores (4322-020-52520) 1 x former, no tags (4322-021-33020) clamp assembly: 1 x 52PLATE 1 x 55UBOLT 2 x 632NC2A

Two 7-lug tagstrips; two 5-lug tagstrips; one 3-lug tagstrip; chassis or box as required; winding wire — 1 mm and 0.4 mm enamelled copper wire; 32 x 0.2 mm hookup wire; 10 x 0.2 mm hookup wire; nuts, bolts etc.

Price estimate $30 — $35

current carrying leads are kept short.

Make sure you have enough room to mount both T1 and T2. A single bolt through the centre hole of the T1 potcores will secure it but use a fibre washer under either the head of the bolt or under the nut to prevent cracking one of the potcore halves.

If you use a chassis that comes in two halves (like we did on our prototype) mount all the tagstrips and components on the one half so that all the ground tie points are connected together whether the case is split in half or not. If you use a box with a lid (like a diecast box, for example) mount all the components and tagstrips either on the lid or in the box, for the same reason.

When you have a layout finalised for the housing you're using, it's best to assemble all the electronics first, leaving the transformers till last. *Then* wind the transformers. Use our Table of Suggested Outputs and the Transformer Winding Details as a guide to assemble the two transformers. When you've done these and checked that all is correct, mount the transformers and wire them up.

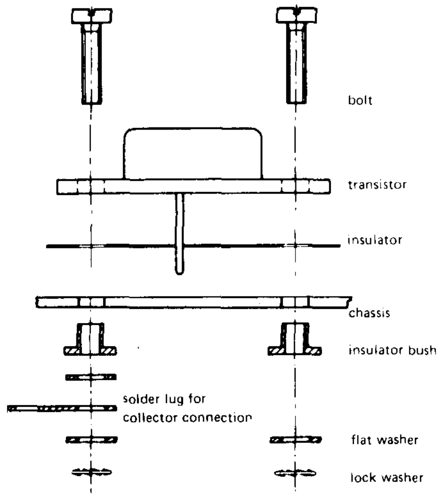
For the dc input leads, use heavy duty cable or hookup wire, remembering that 20 A or so may be passing through it. Don't forget the line fuse.

Firing it up

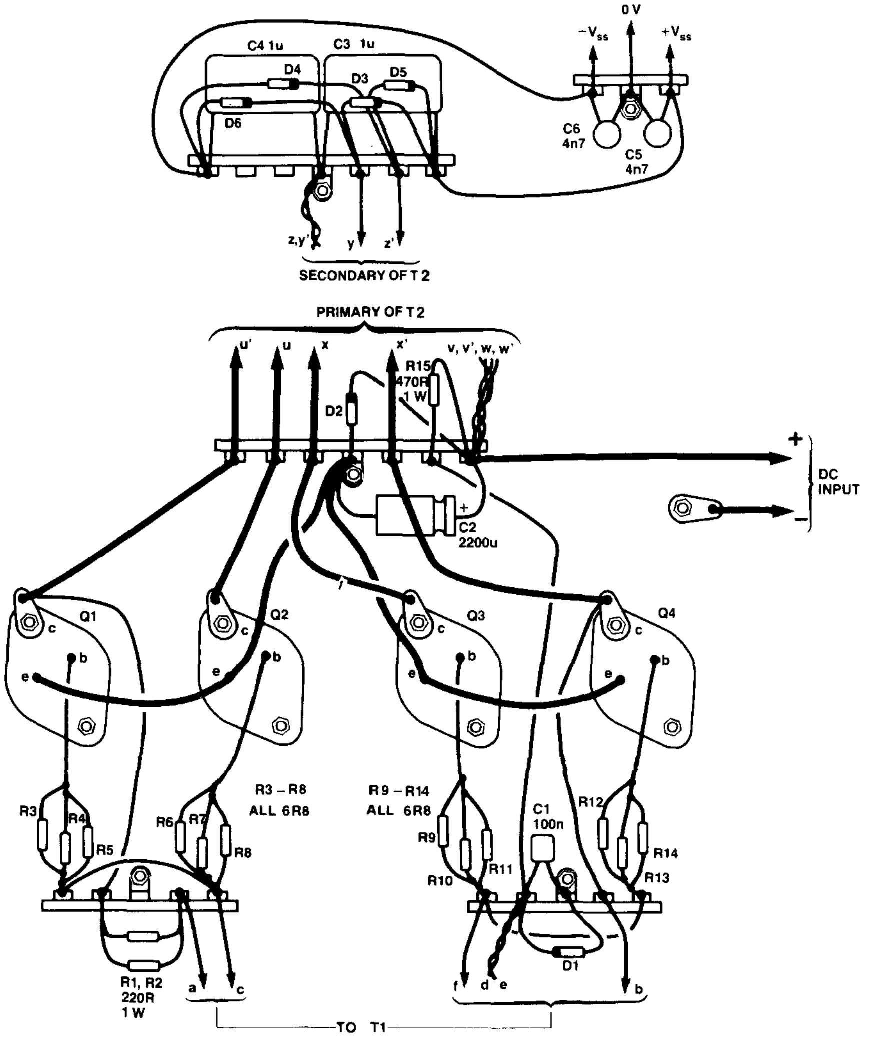
Simple. If you're confident you've wired it up correctly (*and* checked it), hook a multimeter to the dc output and connect power to the dc input. You should hear the transformers 'sing' immediately at quite a high pitch (around 6 kHz if your pitch sense is that good). The output voltage should rise to what you require, also. If you don't hear the transformers sing, then switch off and reverse the primary (a-b) connections of T1. Switch on and the inverter should burst into life. If it doesn't — or worse, bursts into flames! — switch off and take a look at your wiring. Correct any faults before trying again. In particular, make sure you have D1 the right way round.

If all is working as it should, you could try and assemble a 'dummy' load for the output. A suitable set of power resistors will do. The exact resistance will depend on the supply and the load current it has to supply. We'll have to leave this to you.

Under load, the output voltage should be within a few per cent of what you require and power dissipation of the



Mounting the power transistors.



General wiring diagram of the inverter. Layout is not critical. However, use heavy duty (32 x 0.2 mm) hookup wire for the heavy leads shown here for wiring the collectors and emitters of the four power transistors. Capacitors C5 and C6 provide high frequency bypassing of the output rails. Mount them close to where the supply output leads exit the case.

transistors should be quite low. They should only get warm to the touch. (But don't touch them while the inverter's operating — you can get a 'belt'!) You will notice that the operating pitch of the inverter drops when a load is applied.

If all tests out well, hook up the inverter to the unit it is intended to power and try it out. With audio amp modules the 6 kHz oscillation frequency of the inverter should not be audible in the loudspeakers or should be a very, very long way 'down'. Where it is used in conjunction with a sensitive preamp, earthing loops and supply line induction into input leads and earths can cause 'break through' of the 6 kHz oscillation frequency. Take care with the routing of supply leads from the inverter. Keep them away from input leads and make sure the audio equipment is earthed at a single point, either at the power supply chassis or at the dc input common (negative).

Avoid radiation from the inverter inducing 6 kHz breakthrough into any equipment by keeping the inverter physically separate from such equipment. Both transformers have very little external field, but the wiring of the inverter carries considerable switching currents and can induce small, but significant, signals into sensitive audio or RF input leads. If you intend mounting it inside the equipment case, build it in a separate, shielded (i.e: all metal) enclosure and mount that inside the equipment but away from input circuitry.

Performance

This project was hastily built up one Saturday, from a 'lash-up' prototype, to power the ETI-498/499 PA amp for a function the following day! It worked first off. We didn't even have to reverse the primary of T1 to get the feedback phase correct!

Performance was faultless — for both the inverter and the PA.

Occasionally you win some! Breakthrough of the 6 kHz oscillation frequency was only evident with the low level mic gain and the volume pot on the PA amp set full up. Two secondaries were wound on the inverter output transformer (T2), one to provide the power amp with ±50 V and the other to provide the preamp with ±15 V. The breakthrough was subsequently found to be primarily due to a double-earthing problem.

The PA amp ran from a 12 V battery faultlessly for an all-day event. The inverter ran cool — admittedly, it was midwinter and quite cold, but efficiency approaches or exceeds 90% and in this sort of application, average dissipation is very low. ●

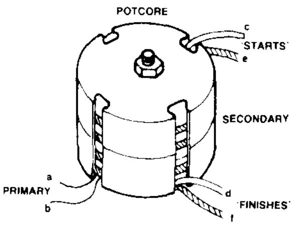
TRANSFORMER WINDING DETAILS

T1

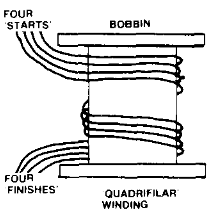
Core	FX2242, 36 mm dia. potcore, two halves with single section bobbin.
Wire	enamelled copper wire, about one metre of 1 mm diameter wire and about 1.5 metres of 0.4 mm.
Primary (a b)	20 turns of 0.4 mm wire wound evenly on the bobbin. Cover with a layer of insulation tape. **Note that b is the start.**
Secondary (c-d, e-f)	4 turns, bifilar wound (see diagram), of 1 mm wire spread over bobbin. Cover with a layer of insulation tape. Bring out the starts at one end of the bobbin, **finishes at the other. Starts are c and e.**
Notes	The above refers to T1 wound for a **12 V (nominal) supply.** On a **24 V (nominal) supply,** the primary (a-b) and secondary (c-d, e-f) should be doubled (i.e: 40 turns and 8 turns, bifilar, respectively). On a **32 V (nominal) supply,** the primary turns (a-b) should be increased to 50, the secondary (c-d, e-f) to 10 turns, bifilar.
Winding order	Wind the primary (a-b) **first.**

T2

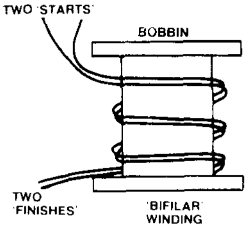
Core	Philips EC-core assembly, as per the parts list.
Wire	enamelled copper wire, 0.4 mm dia. — length to suit application, and about two metres of 1 mm dia.
Primaries (u-v, u'-v', w-x, w'-x')	use 1 mm wire wound **quadrifilar** (see diagram), two volts per turn. i.e: for 12 V (nominal) supply — six turns; for **24 V (nominal) supply** — 12 turns; for **32 V (nominal) supply** — 16 turns.
Secondary (y-z, y'-z')	0.4 mm or 1 mm wire (to suit current) bifilar wound, two volts per turn. i.e: for **±40 V supply rails** — 20 turns; for **±50 V rails** — 25 turns, etc. See table of suggested outputs.
Winding order	Wind the quadrifilar primaries (u-v, u'-v', w-x, w'-x') **first.** Cover with two layers of insulation tape.

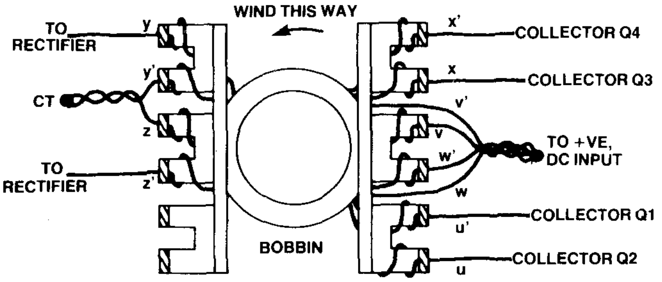


T1 ASSEMBLY



STARTS: u, u'; w, w
FINISHES: v, v'; x, x'





WINDING T2

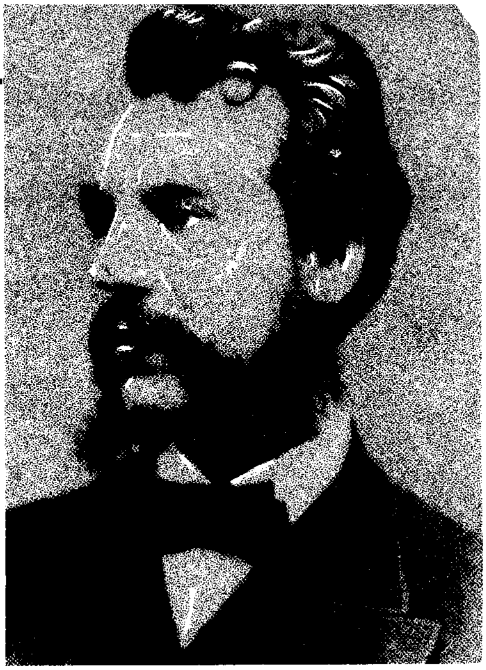
TABLE OF SUGGESTED OUTPUTS

OUTPUT	T2 SECONDARY	RECTIFIER	APPLICATION
±50 V	25 turns bifilar	2 x fullwave	Power 2 x ETI-477 (Series 5000) or 1 x ETI-498 module.
±40 V	20 turns bifilar	2 x fullwave	Power 2 x ETI-480 (50 W or 100 W versions) or 2 x ETI-470 modules.
±15 V	8 turns bifilar (Note 1)	2 x fullwave	Auxiliary secondary to power a preamp. e.g: ETI-481M guitar mixer/preamp or ETI-498 PA preamp.
1400 V	700 turns (Note 2)	voltage doubler (Note 2)	Power ETI-565 laser
12 V (from 24 V or higher dc input)	7 turns (Note 1)	fullwave bridge	Power 12 Vdc equipment from 24 V or higher dc input.

Note 1. This takes rectifier voltage drop into account.
Note 2. The secondary can drive the ETI-565 laser power supply directly, replacing the original power transformer.

Project 918

Build a 'photophone' light beam transceiver



Bell, inventor of the photophone, pictured in 1876, the year he patented the telephone.

Unlike the telephone, the photophone is probably Alexander Graham Bell's most obscure invention. Instead of wires, you can talk on a beam of light. This modern — solid state! — version is simple to build and remarkably effective.

Phil Wait
William Fisher

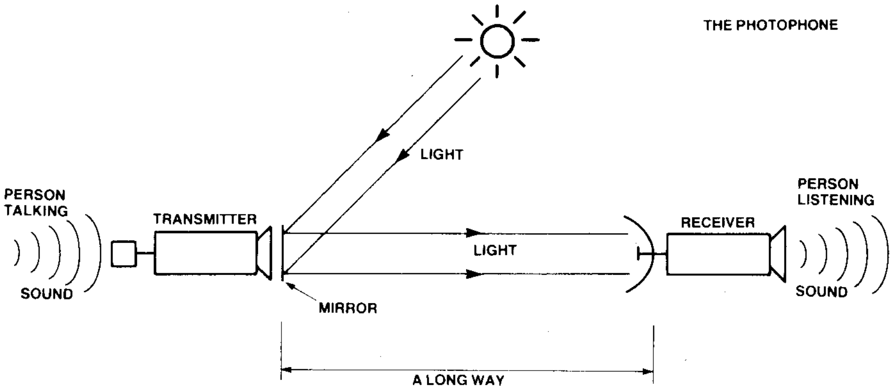
A PHOTOPHONE is a device for sending voice signals along a light beam. The word 'photophone' dates from 1880, when Alexander Graham Bell coined it to describe his own light-beam communication system. At his death in 1922, Bell was still convinced that the photophone was his most important invention, more important even than the telephone, which by that time had spread into a worldwide network.

However, the world in general disagreed with Bell and went ahead with communication systems using wires or radio waves as carriers, in preference to light waves. (The development of fibre optics may reverse this trend, but that's another story.) The photophone was forgotten by everyone except a few historians of science.

In the interests of nostalgia and entertainment we have revived this ancient invention, using some modern electronics instead of the cumbersome and unreliable modulation and detection equipment that Bell was forced to use. (He was working in the pre-electronic age, nearly thirty years before triode valves were invented and seventy years before transistors.)

The principle

The basic principle of the photophone is that a normally flat mirror is made to flex slightly by sound waves impinging on it. A light beam is reflected off the mirror and aimed at a photosensitive receiver. As the mirror is flexed by the sound waves it becomes alternately convex and concave, which means that the beam reflected onto the receiver becomes alternately wider and narrower, in time with the sound wave. The total number of photons in the light beam is not altered by these changes in its width, but the fraction of that energy which falls on the receiving surface does vary (providing the beam is always wider than the receiver). So the intensity of the light received varies with the width of the light beam, which in turn varies with the curvature of the mirror, which is caused by the pattern of sound waves hitting it.

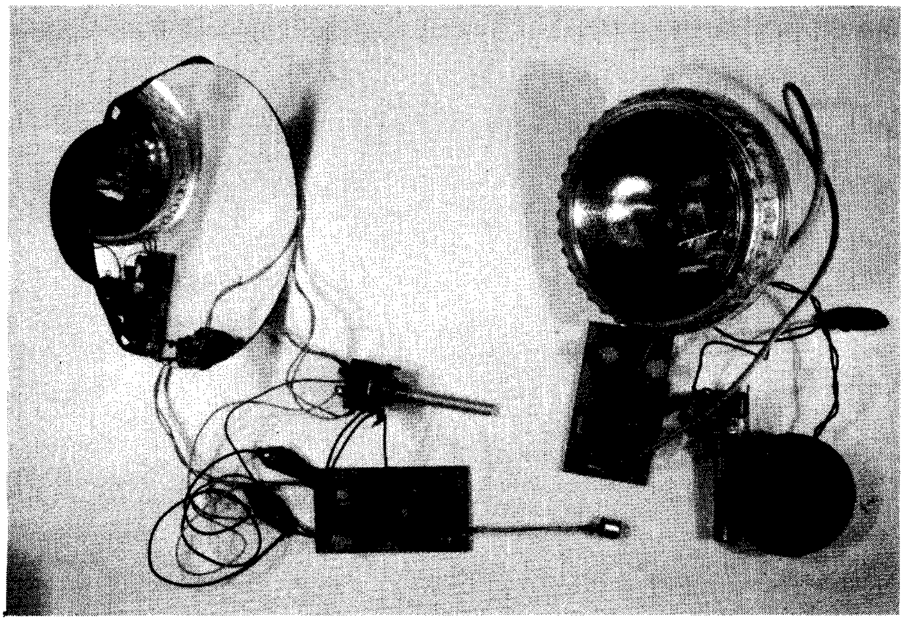


Illustrating the basic principle of the photophone.

The variations in light intensity at the receiver can be converted into an electrical signal which drives a loudspeaker via an amplifier to reproduce the sounds originally produced at the transmitting end. The whole arrangement is a kind of amplitude modulation of the light beam, with the mirror acting as the modulator and the photosensitive surface acting as the demodulator.

Transmitters

The first problem is to make the mirror flex in time with the sound wave. Bell's original mechanism for doing this was very simple. He used a thin mirror ▶



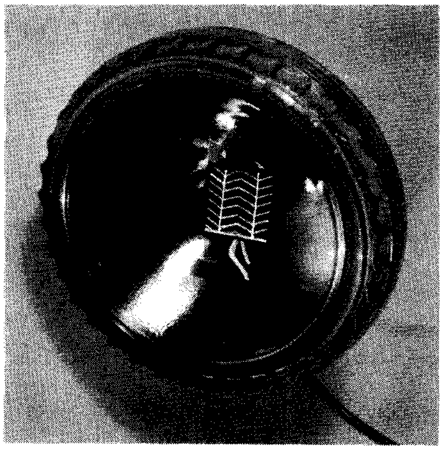
The assembled prototype transmitter and receiver. The transmitter was powered by a 6 V lantern battery, the receiver by a 9 V transistor radio battery. We used a solar cell mounted in a lantern reflector, as described below.

firmly glued over the end of a flexible tube. When he spoke into the other end, sound waves travelled down the tube to make the mirror vibrate. This method is quite effective and you can use any kind of tube — a rigid cardboard or metal cylinder, for example. The mirror is more of a problem, because it needs to be quite thin to flex enough in response to unamplified voices. You may be able to obtain an ultra-thin glass mirror from a scientific equipment supplier, but some kind of reflective foil will be easier to get. Ordinary aluminium foil is an excellent reflector but it tears easily and it's hard to keep it uncreased, although these problems can be avoided to some extent by sticking adhesive tape to the back of the foil. Aluminised mylar (or other plastic) foil is probably best, if you can find any.

For our own transmitter we opted to use a circular glass mirror of normal thickness, such as you might buy in any chain store as a shaving mirror (the flat variety — not concave). We mounted this on the frame of a 150 mm diameter circular loudspeaker and made an amplifier to drive the speaker with sufficient power to flex the mirror. If you want to use this method, buy the speaker first, then look around for a shaving mirror the same diameter or slightly larger. Remove the metal or plastic rim and you will usually find two mirrors, one flat and one concave. Discard the concave mirror and glue the flat one to the metal rim (NOT the cone) of the speaker, using epoxy resin. Don't use a silicone compound like Silastic, because the joint must be rigid. The wider the speaker and mirror you use, the better the range and the lower the distortion, because a wider mirror can flex more. The amplifier and microphone are described under 'Electronics'.

Receivers

There are several photosensitive devices which might be used in a receiver. Light dependent resistors respond too slowly, but a phototransistor is much faster and could certainly be used. Bell's original photophone receiver used selenium photoresistors in series with a battery and a telephone earpiece, but he had great difficulty with this system. (Bell deserves credit for any success with this astonishingly crude arrangement. As Dr. Johnson remarked about a dog walking on its hind legs — it was not done well, but it is astonishing that it was done at all!)



Close up of our receiver input device. This consists of a small solar cell piece mounted in a reflector taken from a 'Dolphin' lantern. To mount the cell, we cut a slot in one side of the reflector, put Silastic on the rear of the solar cell (leads already attached) and inserted it in place. It proved very effective.

For our receiver we opted to use a 'solar cell', which is a kind of silicon photodiode. The large area and easy availability of solar cells make them the best choice overall. The effective area of the cell was made even larger by mounting it near the focus of a parabolic reflector taken from a hand lantern and an even larger effective area could be obtained by using a car headlamp reflector. Bell's original photophone used a reflector nearly a metre in diameter to gather the light, but anyone thinking of using very large reflectors should remember that the reflector must not be wider than the beam it is collecting, otherwise the modulation cannot be detected.

Light sources

In principle any light source will work. At night, with no other lights nearby, a pocket flashlight has been reported to work by some experimenters, but we haven't tried this ourselves. In daylight you need an intense and collimated (i.e: parallel) beam to get any reasonable range. A gas laser (such as a helium-neon type) is an ideal source, which in principle could give you a range of several kilometres in open country or over water, but some precautions are necessary. A low power laser is safest, preferably one having an output of one milliwatt. If possible, a 'beam expanding telescope' should be fitted to it. This increases the diameter of the beam making it easier to aim and reducing possible harmful effects to the eyes of any person who may accidentally look into the beam. The person setting up the receiver should not look toward the laser. Note that the beam at the receiver must be larger than the receiving device. This is where a beam expanding telescope helps.

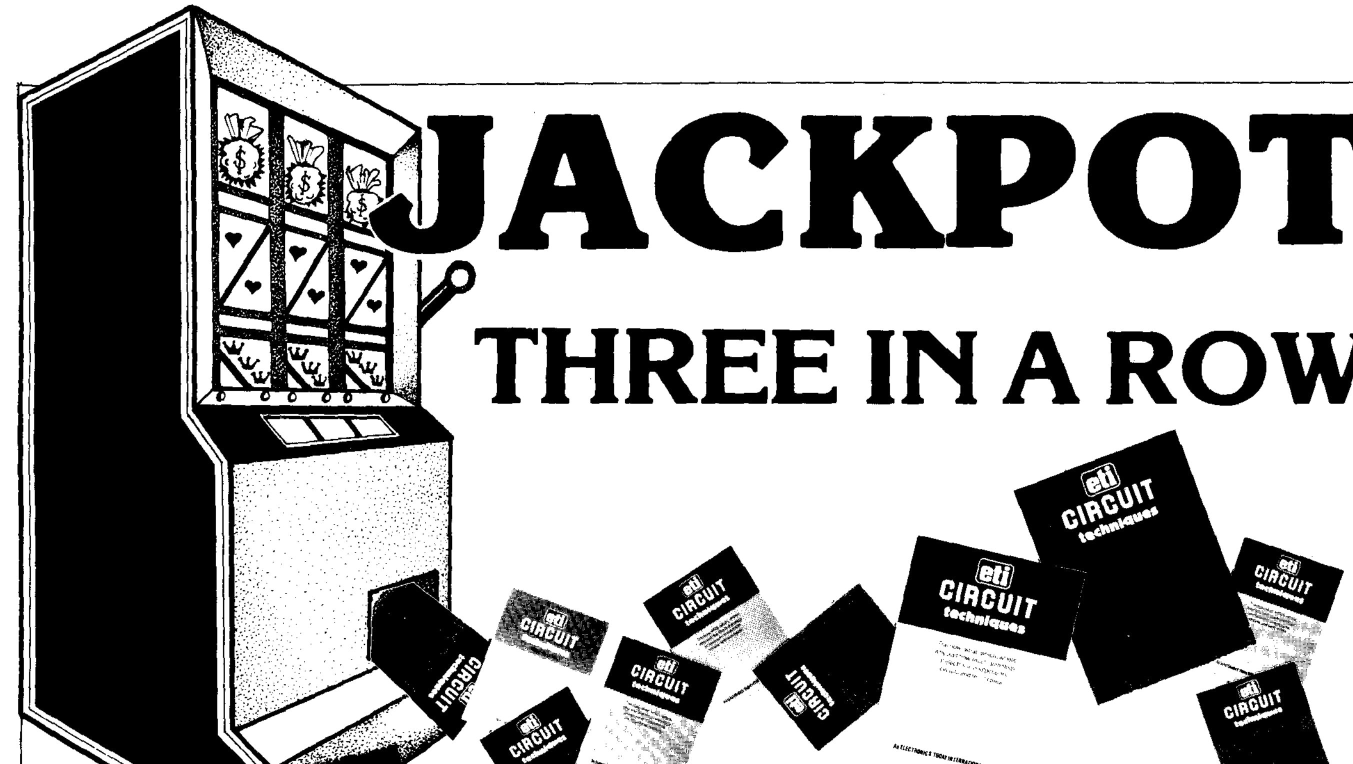
This project makes a good 'science demonstration' project if your school science department has a suitable laser.

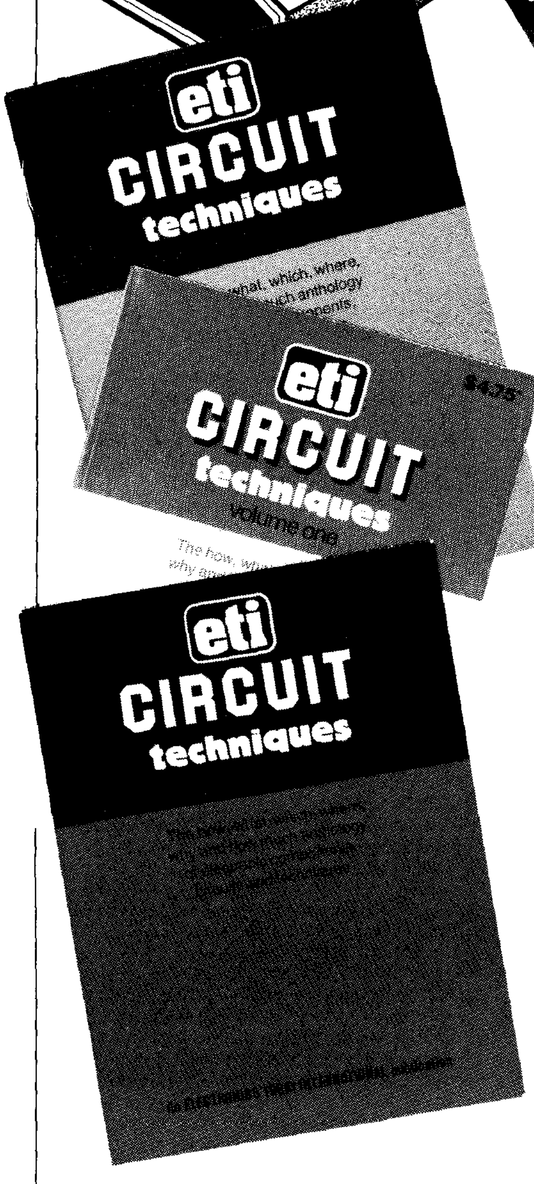
However, a much more readily-available light source is the Sun whose light output is quite intense and has reasonably parallel rays. Using reflected sunlight, we found that we could communicate intelligibly by photophone over distances of a few hundred metres. With more efficient transducers (ours were deliberately simple) this distance could probably be extended.

▶

JACKPOT

THREE IN A ROW





CIRCUIT TECHNIQUES

It's alright 'painting by numbers' and building projects described in electronics magazines, but when you really want to build something that isn't a project, hasn't been a project and is maybe unlikely to be a project by the time you want it — then you need to know how to go about getting that circuit together for yourself.

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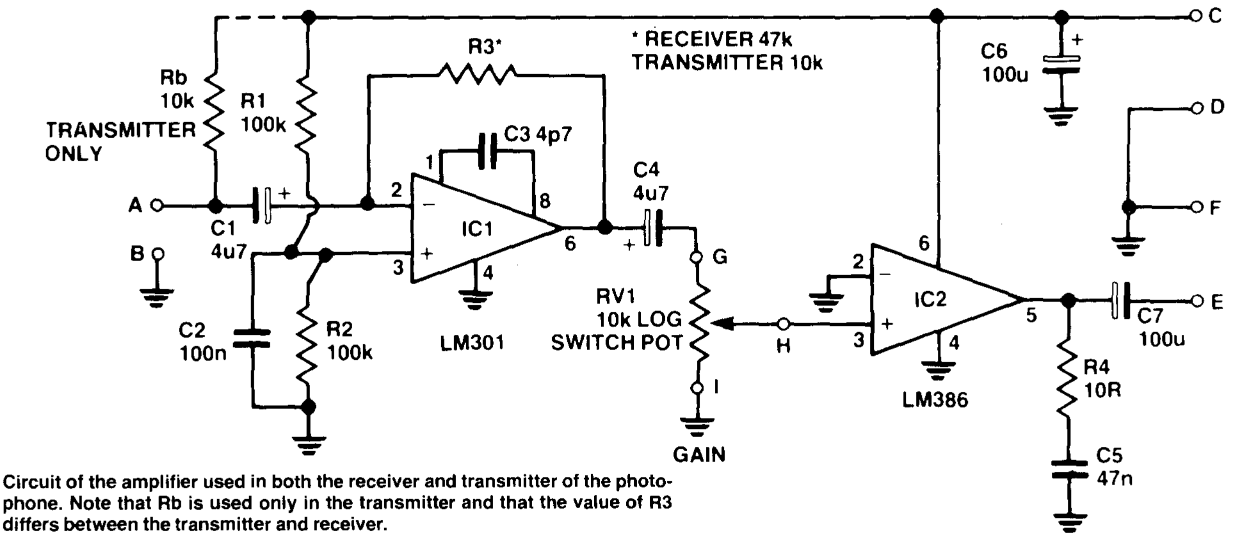
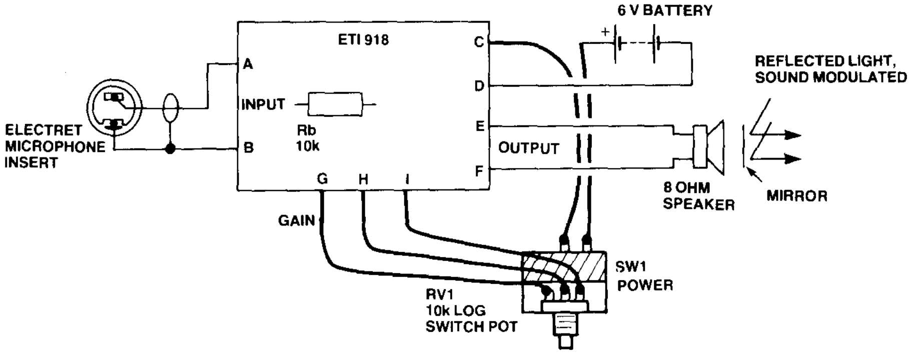


Circuit of the amplifier used in both the receiver and transmitter of the photophone. Note that Rb is used only in the transmitter and that the value of R3 differs between the transmitter and receiver.

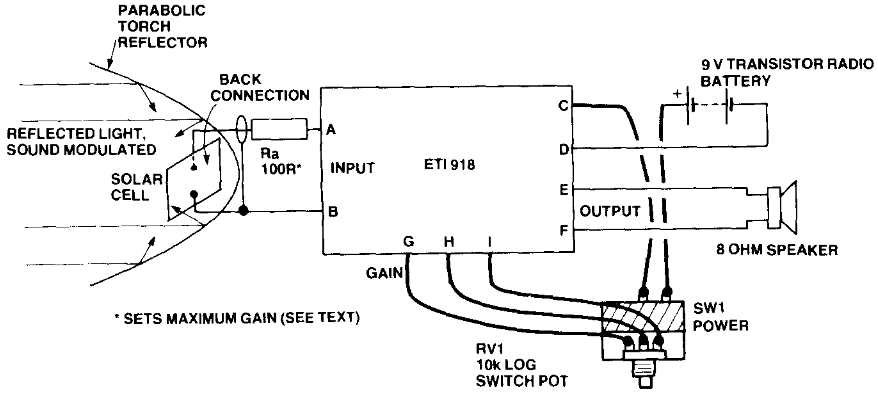
Electronics

To amplify speech to drive the loudspeaker of the transmitter, we designed a simple amplifier around two ICs — an LM301 voltage amplifier and an LM386 power amplifier. There was no point in making a low noise, low distortion amplifier because the transmitting and receiving transducers are relatively noisy and non-linear. However, performance is quite acceptable. Speech signals from an electret microphone insert are amplified by the LM301, then attenuated by a gain-control potentiometer before being fed to the LM386, whose output drives the loudspeaker. The large speaker needs a lot of current to drive it, so a six volt lantern battery is the best kind of power supply.

The receiver uses a very similar amplifier to boost the tiny signal derived from the solar cell, the dc component of this signal being blocked by a capacitor. The receiver amplifier is so similar to the transmitter amplifier that it uses the same pc board design. The only differences are that the feedback resistor (R3) around the LM301 op-amp has a larger value in the receiver to give



Wiring diagram of the photophone transmitter. Note the wiring to the rear of the electret microphone insert. You'll find one connection attaches to the mic case. This is the 'common' and goes to B on the pc board. Some inserts have leads already attached. Usually the common lead will be black. Use a shielded lead between the mic and the input to the amp.



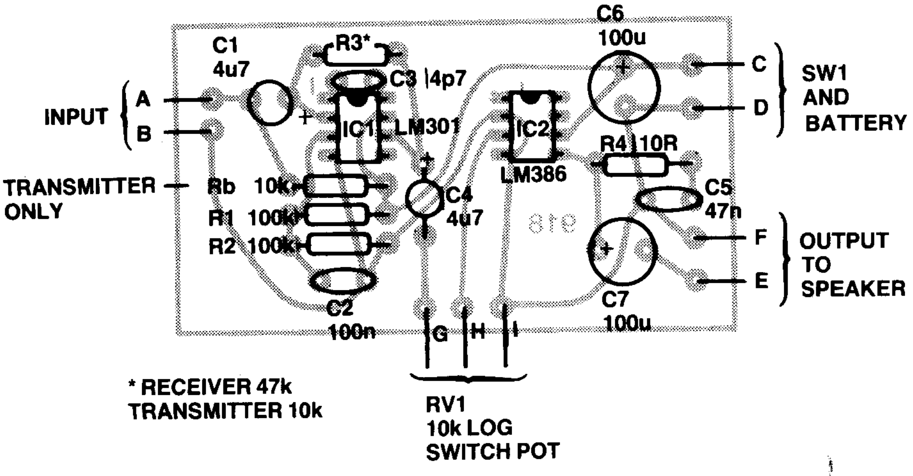
Photophone receiver wiring diagram. Use a shielded lead between the solar cell and the amplifier input. Don't forget to connect a 100 ohm resistor in series with the lead to terminal A on the amp.

HOW IT WORKS — ETI-918

Sound received by an electret condenser microphone is amplified by the transmitter amplifier and used to drive a loudspeaker. A plane (i.e: flat) mirror attached to the housing of this loudspeaker is flexed by the sound wave emitted by the speaker, so that it becomes alternately convex and concave as the sound pressure increases and decreases. A beam of sunlight reflected by the mirror onto a solar cell at the receiving end becomes broader or narrower as the mirror flexes, in phase with the sound pressure variations. Providing the beam always completely covers the collecting surface, a broader beam means that fewer photons are collected by the solar cell and a narrower beam means that more photons are collected.

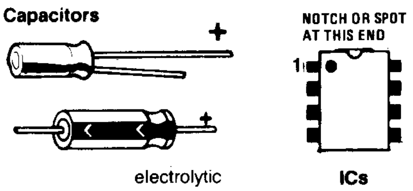
The variation in the number of photons collected causes a proportional variation in the current generated by the solar cell. These current variations cause variations in the voltage across resistor Ra, and these voltage variations are amplified by the receiver amplifier, which drives a small loudspeaker to reproduce the sounds spoken into the transmitter microphone.

The transmitter and receiver amplifiers are essentially similar, each using an LM301 op-amp (IC1) for voltage multiplication and an LM386 power amplifier (IC2) with a switch potentiometer (RV1) between these two ICs for manual gain control. Resistor Rb (in the transmitter amplifier only) provides bias for the electret microphone. Capacitor C1 blocks dc signals. The gain of IC1 is set by the ratio of the resistance of R3 to the impedance of C1 at audio frequencies. The potential divider formed by R1 and R2 biases the non-inverting input of IC1 up to half the supply voltage, so that IC1 can be used with a single ended supply. C4 blocks any dc offset of IC1's output, R4 and C5 prevent instability around the output stage and C8 prevents any dc offset from being applied to the speaker. C4 and the internal resistance of the battery form a low-pass filter that removes battery noise from the supply line.



Component overlay for the amplifier. Note that Rb is not needed in the receiver amplifier and that the value of R3 differs between the transmitter and receiver.

COMPONENT PINOUTS



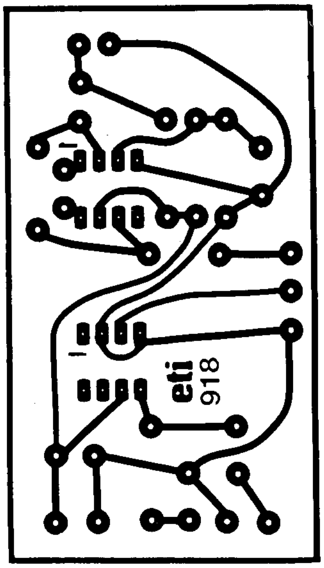
higher gain, and the transmitter has an extra resistor (Rb) to bias the microphone. Only a small speaker is necessary for the receiver, so that a nine volt transistor radio battery can be used as power source.

Construction

We haven't designed any kind of box for this project. Obviously permanent housings for the transmitter and receiver will make the photophone much easier to use, but you can't make them until you've done some experimenting and finally decided what shape and size of reflectors you are going to use. In any case, this is a magazine about electronics, not carpentry or metalwork!

The two amplifiers should present no difficulties in assembly, providing you remember the usual precautions — check the orientation of capacitors, diodes and transistors, use a smallish bit when soldering the IC pins and let the ICs cool down for a few seconds between soldering each pin.

The electret microphone insert is polarised, so it can only go one way round. Make sure you solder the negative lead (usually black) to point B on the pc board and the positive lead



Printed circuit board artwork, full size.

(usually red) to point A. Glue the flat mirror to the metal rim of the transmitter loudspeaker (not to the cone), using epoxy resin (not any other adhesive).

Some solar cell pieces come with leads attached, some do not. If you have to attach your own leads, do it very carefully, using a low wattage iron and thin flexible wire. Most cells have electrodes on the front and back surfaces: solder to the back electrode first, by forming a small pool of solder near the edge of the cell and holding the end of the wire in the pool until it cools. The front electrode is usually in the form of a thin strip and needs more care. Apply enough solder to form a bump or ridge, reheat the solder and position the second wire. The leads must be protected from strain and can be glued to the reflector if one is used. Connection to the amplifier should be made through shielded cable. Don't forget to insert the 100 ohm resistor (Ra) in series with the lead that connects to point A on the pc board (see the overlay diagram). The solar cell can be held in position with plasticene while you are experimenting, or with silicone compound (such as Silastic) for a more permanent bond.

Operation

Leave the receiver with a friend and walk in the direction of your shadow, then point the transmitter so that the sun's reflection is directed at the receiver. It helps to put the receiver in the shade, so that you can see the spot of light from the transmitter mirror more easily.

You'll find that only a very small movement of the transmitter is enough to move the spot off the receiver, so it's easier if, once you've got the direction approximately right, you keep the transmitter steady on the ground or on a table and move the receiver to make the fine adjustments. Alternatively, you could keep the receiver fixed and mount the transmitter on a tripod.

A word of warning — don't point the light beam at your assistant's eyes (or anyone else's) if you're using the sun as the light source. To be safe, wear sunglasses (half-silvered types cut out most light) and never look directly at the mirror. ●

PARTS LIST — ETI-918

The following is a list of parts needed to build an electronically amplified transmitter and receiver to our specifications. The numbers in brackets represent the total number of components required of that value or type. If you are not using an amplifier in your transmitter, you will only need one of each component listed (i.e: one of R1, one of R2, etc.)

Resistors	all ½ W, 5%	
R1, R2	100k (4)	20
R3	(2) see text	10
R4	10R (2)	10
Ra	100R (1)	[illegible]
Rb	10k (2)	[illegible]
Potentiometers		
RV1	10k log. switch pot	[illegible]
Capacitors		
C1, C4	4u7/16 V RB electro. (4)	
C2	100n greencap (2)	
C3	4p7 ceramic (2)	
C5	47n greencap (2)	
C7, C8	100u/16 V RB electro. (4)	
Semiconductors		
IC1	301 op-amp (2)	[illegible]
IC2	386 power amp (2)	[illegible]

Miscellaneous
One or two ETI-918 pc boards, one electret microphone insert, small solar cell piece, parabolic torch reflector, small 8 ohm speaker, 150 mm 8 ohm speaker, 150 mm or larger diameter round mirror to match diameter of speaker, 6 V lantern battery, 9 V transistor radio battery, short length of shielded cable, insulated hookup wire.

Price estimate

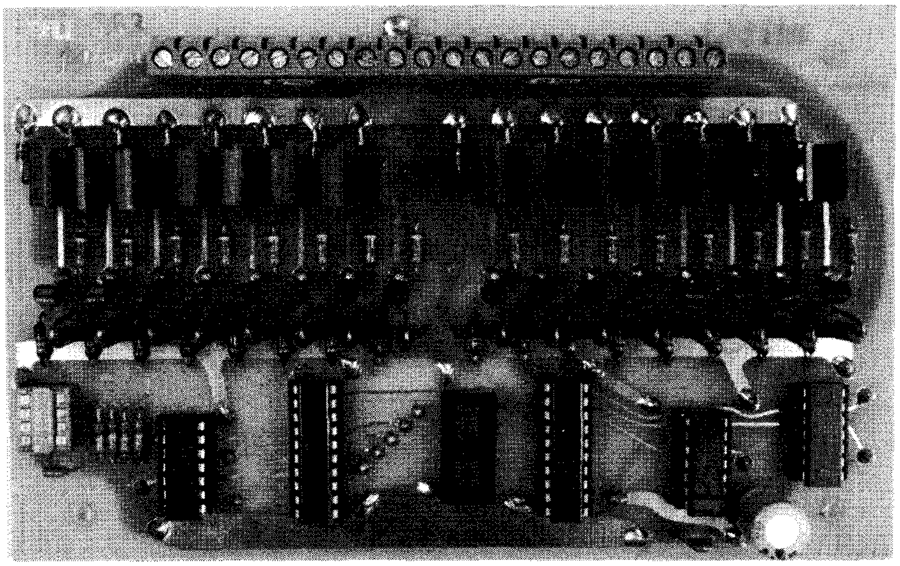
$35 — $40	**$22 — $25**
(complete)	(electronics only)

Project 653

16 Channel computer output driver

With this project hooked up to your computer you can drive relays, motors, lamps, solenoids, or whatever, under software control. Do something useful with your computer!

Geoff Nicholls



The project is built on a board measuring 103 x 165 mm.

A PERSONAL COMPUTER need not necessarily be used for playing games, learning programming or producing computer club newsletters. With this project, you can put it to some *practical* use. Just what that is I'll have to leave to your imagination and ingenuity!

Two independent groups of eight outputs are provided. Each of the 16 output driver circuits is configured to run from a 12 V supply, although higher supply voltages may be used. Each can be configured to sink up to 3 A. Simple address selection for the board is provided by an on-board DIP switch. It's a pretty straightforward project and you can vary things to suit your application(s).

Component options

The component values shown in the circuit diagram are for output currents of up to 2 A. If other load currents are desired, then a few components need changing in order to reduce power dissipation in the output transistors.

For currents of less than 1 A, the TIP31Bs (Q17-32) may be replaced by BD139s — which have the distinct advantage of costing considerably less than TIP31Bs. However, note that BD139s have a different pinout such that the metal face on BD139s is on the opposite side of the package to the TIP31Bs.

The base current drive to the output devices is determined by R17 and R32 and may be optimised for different loads. The table here (Table 1) summarises component values for various output currents.

If the total output current is expected to exceed 20 A for more than a few minutes, then it is advisable to make the following changes:

(a) Use a terminal strip capable of passing half of the total load current through each terminal OR solder the power ground directly to the pc board ground plane.

(b) Solder several lengths of tinned copper wire to the heavy power ground track on the pc board.

Intermittent use over 20 A should not require these changes. The power dissipation calculations for transistors Q17 to Q32 were based on data for RCA-manufactured TIP31Bs. The prototype transistors developed a collector-emitter voltage of 0.65 V at 2 A, which does not necessitate heatsinking the transistors. If high current loads are to be used, measure Vce and Ic and calculate P = Vce x Ic.

TABLE 1. Component variations

OUTPUT CURRENT amps	Q17 to Q32	R17 to R32	R1 to R16	+5 V SUPPLY CURRENT (max.)
3	TIP31B	15R/1W	330R	3.4 A
2	TIP31B	18R/1 W	470R	2.8 A
1	TIP31B	22R/½ W	470R	2.3 A
<1	BD139	33R/½ W	470R	1.6 A

The TIP31B can dissipate 2 W at 25°C ambient without heatsinking. Continuous use at high currents may require a small flag heatsink on each TIP31B.

Construction

The entire electronics for this project is mounted on a double-sided pc board. During the early design phase, it was found that a single-sided pc board would require an unacceptably huge number of links. To keep the cost down, through-hole plating was not specified for this board and connections between top and bottom side tracks are made with links of 22 swg tinned copper wire, of which there are a total of 61. IC sockets were installed on the prototype, but these are not essential.

Commence construction by giving the pc board a good inspection, looking for broken tracks and undrilled holes. Make sure the tracks are clean and bright so that soldering is easily carried out. Insert all the links first. These are identified on the component overlay diagram by a •. Note that a large star is next to a '62nd' link more or less in the centre of the board. This is the optional 0 V link — see the text under the heading 'Power supplies'.

Next, solder diodes D1 to D17 in place. Note that the cathodes of these diodes are soldered on the *component* side of the board. Solder resistors R1 through T16, then R33 through R48 in place next. Mount and solder the BC639 transistors, Q1 to Q16, in place next. All the 1 W resistors, R17 through R32, stand up on end and these may be soldered in place after the transistors. Follow with the remaining four resistors and the three capacitors. Now you can mount and solder in the output devices, Q17 to Q32. Watch orientation.

Now mount DSW1, but take care you put it round the right way. The ON position of the switches should be adjacent to the edge of the board. If you're using IC sockets, put these on next. If not, solder the ICs in place. Note that ICs 1, 2 and 5 are CMOS types, so take precautions in handling and soldering them in place. Only handle them by the ends of their cases after discharging yourself against an earthed metal object. Solder the supply pins first. A 16-pin DIL IC socket is used for the input connections and this can be mounted now. Last of all, mount and solder in the output terminal strip or strips. We used one 12-way and one 8-way strip as we could not obtain a single 20-way strip.

Having completed the construction, go over the board very carefully, looking for missed links and components, bad joints or mis-oriented semiconductors. Fix any faults and, if you're satisfied all is well, the best way to test the board is to hook it up and try it out!

Power supplies

The logic power supply of +5 V should be supplied from the host computer Vcc rail through the DIL socket pins 15 and 16. The computer's ground (0 V) should be connected to pin 9.

The +5 V power to the driver circuits should not come from the host computer unless it has the capability to supply at least an extra 3 A. In any case, heavy wire should be used (at least 24 x 0.2 mm hookup wire) for the power connections to the terminal strip to minimise voltage drop.

The optional 0 V link (marked with a star) should only be used for light loads. Normally, the connection between 0 V logic and power should be at the power supply.

The output drivers' power supply is shown as +12 V, but other voltages may be used, up to about 70 V. The PIV rating of diodes D1 to D16 should not be exceeded, however (best use 400 V diodes here, at least).

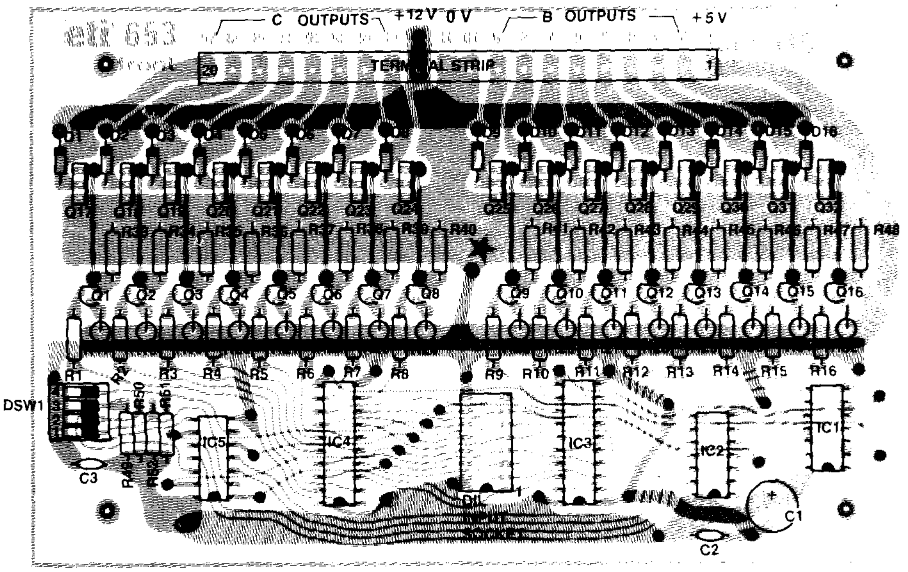
Hooking it up

The ETI-653 has been designed to allow up to eight boards to be connected to a computer through a single ribbon cable. In order to do this a special strobe signal must be supplied by the computer whenever any of the ETI-653 boards are being selected. This will probably require a small hardware circuit, unless your computer is favoured by the famous Murphy! If there is sufficient interest we may publish a general purpose interface board, but until then you will have to work out for yourself how to connect a particular computer from the following guidelines. (For background information, refer to ETI August '82, *Turtle Interfacing Fundamentals.*)

I will assume that the computer has an I/O scheme with eight I/O address lines — AD0 to AD7. The ETI-653 inputs A0 to A3 are then connected to the lowest four I/O address lines of the computer. i.e: AD0 to AD3. Each ETI-653 board is then set up at a different address via the DIL switches, DSW1, 2 and 3. This means that the ETI-653s will occupy 16 consecutive I/O ports. Now for the hard part!

The STROBE input (A4) must have a positive or negative going edge (see the How it Works) that occurs when an I/O WRITE to the ETI-653s is taking place. In order to fully decode the I/O port address space, the other I/O address lines (AD4 to AD7) must be gated with the I/O control signals to produce the STROBE signal. In order to get the STROBE transition timing correct, a signal such as WRP (write pulse) should also be gated in the STROBE logic. This allows the data buss to settle before the latches are locked.

The ribbon cable requires a buffered driver for each wire carrying logic signals, especially if multiple ETI-653s or long cable runs are envisaged. ▶


C OUTPUTS
+12 V
0 V
B OUTPUTS
+5 V
eti 653
TERMINAL STRIP
20
1
D1 D2 D3 D4 D5 D6 D7 D8 D9 D10 D11 D12 D13 D14 D15 D16
Q17 Q18 Q19 Q20 Q21 Q22 Q23 Q24 Q25 Q26 Q27 Q28 Q29 Q30 Q31 Q32
R33 R34 R35 R36 R37 R38 R39 R40 R41 R42 R43 R44 R45 R46 R47 R48
Q1 Q2 Q3 Q4 Q5 Q6 Q7 Q8 Q9 Q10 Q11 Q12 Q13 Q14 Q15 Q16
R1 R2 R3 R4 R5 R6 R7 R8 R9 R10 R11 R12 R13 R14 R15 R16
DSW1
R49 R50 R51 R52
IC5
IC4
IC3
IC2
IC1
DIL
1
C3
C2
C1

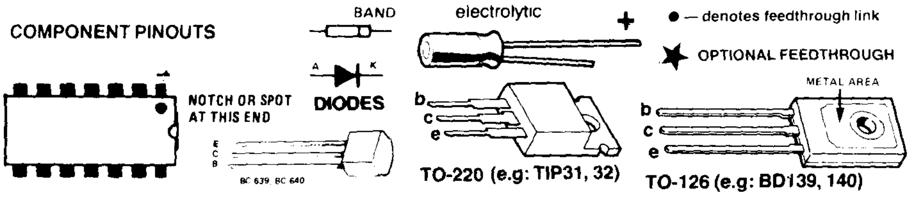
PARTS LIST — ETI-653

Resistors	all ½ W, 5% unless noted
R1-16,33-48	470R
R17-32	18R, 1 W
R49-52	10k
Capacitors	
C1	100u/16 V RB electro.
C2,C3	100n blue chip ceramic
Semiconductors	
D1-D16	1N4002,1N4004 etc
IC1	74C02
IC2	74C00
IC3,4	74LS374
IC5	74C86
Q1-16	BC639
Q17-32	TIP31B,BD139 (see text)

Miscellaneous

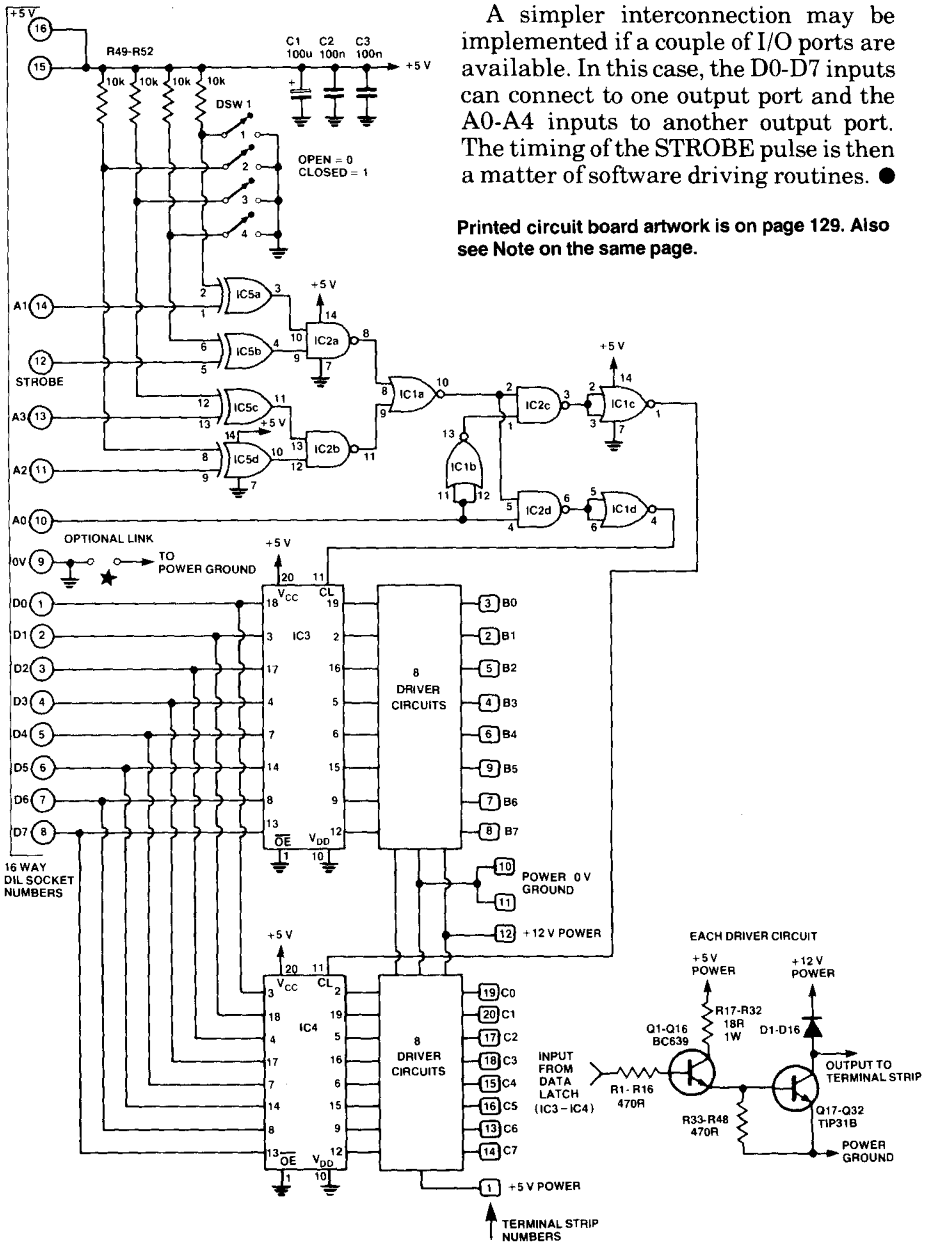
ETI-653 pc board; DSW1 — 4-way DIP switch; 16-pin DIL socket; IC sockets (optional) — 3 x 14-pin, 2 x 20-pin; 2 x 16-pin DIP headers; 1 x 12-way and 1 x 8-way pc mount terminal strips or 1 x 20-way type; suitable length 16-way ribbon cable; 22 swg tinned copper wire, etc.

Price estimate
$40 — $45



A simpler interconnection may be implemented if a couple of I/O ports are available. In this case, the D0-D7 inputs can connect to one output port and the A0-A4 inputs to another output port. The timing of the STROBE pulse is then a matter of software driving routines. ●

Printed circuit board artwork is on page 129. Also see Note on the same page.



HOW IT WORKS — ETI-653

First of all, note that the component values shown on the circuit diagram are for the 2 A output version. Other output current versions are possible, as explained in the text, but basic circuit operation is the same.

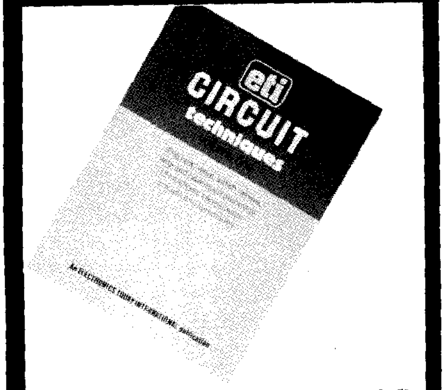
The host processor connects to the ETI-653 board via the 16-pin DIL socket. IC5 compares the logic levels present on the DIL socket pins 14 (A1), 11 (A2), 13 (A3) and 12 (STROBE) to the settings of DSW1, 2, 3 and 4 respectively. When a match is found, pin 10 of IC1 goes high. The STROBE input should receive a pulse edge timed to coincide with a valid data buss (pins 1 to 8 of the DIL socket) and a valid address (pins 11, 13, 14). Note that either a positive-going or a negative-going edge of the strobe pulse may be used, according to whether the setting of DSW4 is closed or open, respectively.

The A0 input on pin 10 of the DIL socket determines which of the two on-board latches are being addressed. When pin 10 is low, IC4 is selected ('B outputs active'), if high, then IC3 ('C outputs active').

Each driver circuit buffers one of the 16 latch outputs and provides an open collector current sink of up to 3 A (see the text on 'Component options').

To simplify the description of the driver circuits, consider the one comprising R1, Q1, R17, R33, Q17 and D1. Diode D1 is a flywheel diode and protects transistor Q17 from excess back emf voltage when turning off inductive loads, such as a solenoid. When the latch output is low, Q1 is held off via R1 and Q17 is held off by R33. Resistor R33 speeds up the turn-off time of Q17 by providing a path to remove stored charge in the base-emitter junction.

When the latch output is high, about 5 mA of current flows into the base of Q1, thus turning it on. R17 sets the base current of Q17 and is chosen according to the output current requirement. Transistor Q17 must be saturated in order to reduce power dissipation and up to 300 mA of base current may be required for 3 A loads (see component options in main text).


HOW?
WHAT?
WHICH?
WHERE?
WHY?
HOW MUCH?

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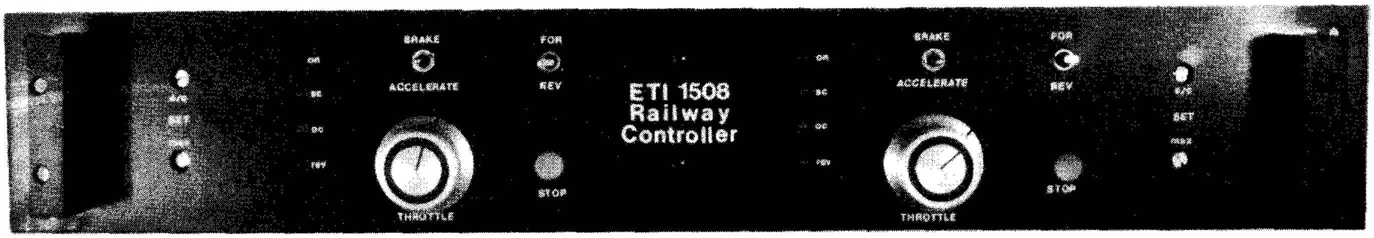
Project 1508

Model train controller simulates 'real' train controls

This model train, or better, railway, controller has controls that operate like 'real' train controls. In addition, it signals open circuit or short circuit conditions on the track and you can make emergency stops.

Jonathan Scott



MODEL RAILWAY controllers are one of those perennial projects which recur every year or so in some magazine or other, because they are almost ideal as a project: lots of people have model electric train sets (what other sort *is* there? Yeh, yeh — steam, but this isn't Steam Train International Today magazine! — Ed.), lots of commercial controllers are either crude or relatively expensive and there are plenty of 'angles' to explore, both electronic and philosophical.

Some controller designs are *cheap*. And that's as it should be, a hobbyist has to start somewhere. Some are designed to employ recently-released innovations. Some use microprocessors and digital tone-encoding techniques to be really comprehensive. Others are designed to make driving the train 'easy' by compensating for loads of hill-climbing or many carriages, etc. It is our belief that these are rather artificial aims, so let's see what *we* think is *really* necessary.

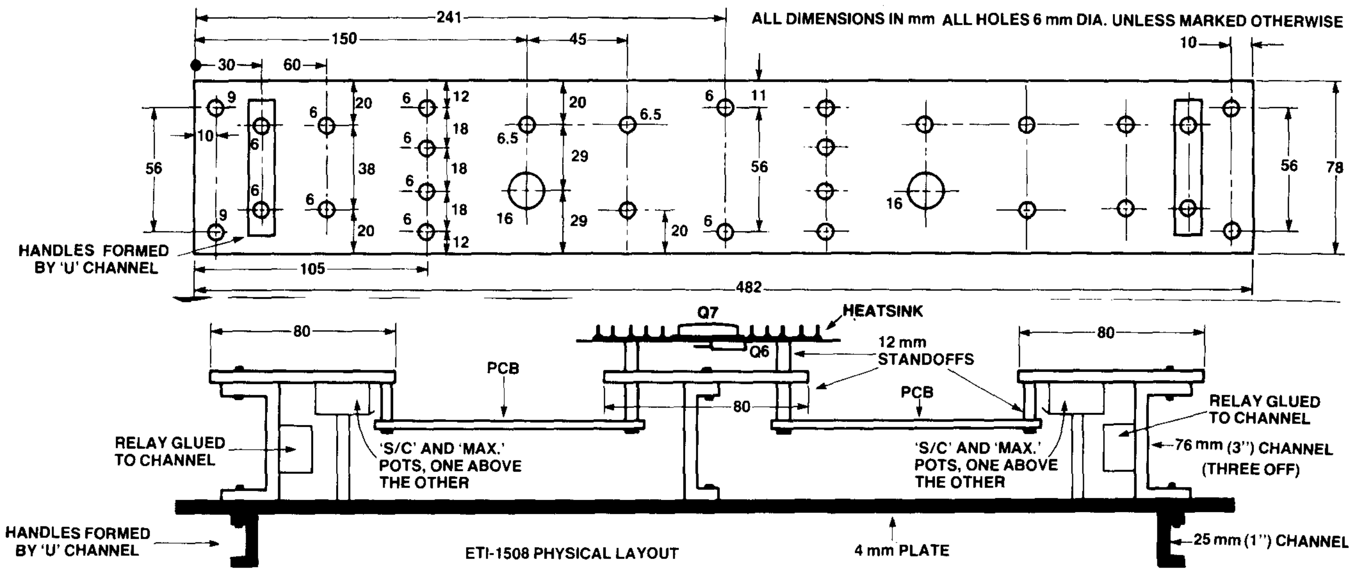
The model railway enthusiast does not just like to see it go, he likes to *drive* the train. So, a controller should pass on to the user as many of the 'inputs' as a real train would encounter, but hide from him unreal inputs which only a model exhibits. In other words, he wants to feel the effect of inertia, but not of bad contacts, feel the engine and brake work separately and to feel the effort of climbing or carrying extra load, but not feel some loss of power when junior gets his train going too, or the butler turns on the mixmaster. In addition, a controller should be able to run everything from a micro-gauge small locomotive to twin O-gauge engines. Finally, it wants to be as inexpensive to build as is possible without sacrificing anything. (After all, if you've got a butler, there's not going to be too much spare cash left to spend on luxuries like model railways!) This is precisely the philosophy adopted for this project. Our new controller has been built in rack panel form with two separate control systems running from one mains step-down transformer. Needless to say, if you want to build 1-to-21 such units in wooden consoles all run from two car batteries, then you can please yourself — our design can be used as a guide for those who want to follow that course. From our experience, hobbyists like to customise their housings.

The front panel of our controller is rather unconventional for a *model* train controller, but somewhat closer to the controls of a real train. One switch selects the thrust applied ("accelerate"), no thrust, or in the momentary (spring-loaded return) position, normal brake. This is the main control, and indeed the only one required for commuter trains such as London's Tube or Le Metro in Paris. Once the throttle knob has been set to define maximum torque, throwing the main lever to ACCELERATE causes a small jerk in the wheels, corresponding to the take-up of slack etc, followed by normal acceleration toward the top speed. Moving the main level to the centre or 'idle' position causes the train to start coasting to a final halt. Pressing it to BRAKE hastens the stop. In metropolitan trains the driver aligns the train correctly in the station by judicious pressing and releasing of the main lever, finally stopping with precision, in spite of the train's great inertia, of a few inches. This you will discover, requires *some skill.*

The throttle knob we have already mentioned. On brief runs, you never reach full speed, so the setting of this control is not critical. It sets final engine torque, and hence speed, after the acceleration is over. This is important on long runs. This control can be internally preset to match the size of model train you have; on the prototype the MAX. SET is a screwdriver preset accessible from the front, but provision has been made for it to be a preset on the pc board if you so desire.

The STOP button is the front panel control corresponding most closely to the 'communications cord' on a real train. It is the one concession to necessity over realism. When pressed it quickly shuts down the controller output, halting the train as rapidly as possible. There are two possible ways of wiring it — one which restarts the train when the button is released and another which requires the mains to be removed before it can be restored. This latter option discourages frivolous use of the STOP button (people don't *believe* it when you put a notice on it saying "Fine — $40 for unwarranted use") and provides some failsafe against accident. It is the option we recommend. This will be further discussed in the construction section.

The forward-reverse switch is the fourth and final driving control. In many normal controllers we have seen, even some with inertia, immediate reverse is possible. This is not the case in real life and not the case on our controller. The switch is 'momentary' in its action. It will only have effect when the *train is stationary*. This further limits the model train driver to abide by the rules of 'realism'. You cannot spoil the▶


ALL DIMENSIONS IN mm ALL HOLES 6 mm DIA. UNLESS MARKED OTHERWISE
241
150
45
30
60
10
9
10
6
20
12
18
6.5
56
38
29
16
78
HANDLES FORMED BY 'U' CHANNEL
105
482
Q7
HEATSINK
80
PCB
Q6
12 mm STANDOFFS
RELAY GLUED TO CHANNEL
'S/C' AND 'MAX.' POTS, ONE ABOVE THE OTHER
76 mm (3") CHANNEL (THREE OFF)
4 mm PLATE
25 mm (1") CHANNEL
ETI-1508 PHYSICAL LAYOUT

effect or cause physical mayhem with it.

Four indicator LEDs are provided. One is for the 'power up' condition and this illuminates when power is applied, extinguishing when the lock out condition exists, such as when the STOP button has been pressed. There are LEDs to warn of an open circuit or a short circuit. The open circuit indicator will also illuminate should the commanded current (according to the throttle setting) be impossible to achieve with the available supply voltage. The short circuit indicator warns when the load impedance drops below a value preset by the user. This value may be set from zero to five ohms. On our prototype this was again a screwdriver adjusted front panel control. There is also a LED indicating when reverse is engaged. In a normal railway system a line is 'one way' and reversing is only used (on any given power supply) for shunting. Thus the warning is given when this wrong-way condition exists.

Construction

As this project is aimed at the enthusiast with at least a basic mechanical and electrical/electronic ability we expect most constructors will tailor the physical construction to suit their own requirements. The following is an outline of the order in which to do things if you intend to more or less duplicate our prototype.

Our prototype fits conveniently behind a 78 mm high standard (19 inch — 482 mm) instrument rack panel. With the heatsink and transformer mounted separately, the whole dual controller is less than 75 mm deep and so will recess conveniently into a model baseboard. It requires a hole of about 455 mm by 75 mm for the panel.

The front panel can be made from a blank piece of aluminium sheet cut to the right size. Kit suppliers may supply predrilled and lettered panels, but if not, it's a relatively simple matter to make your own. First step is to carefully mark out the holes with a soft pencil. Centre punch the hole centres and then drill the holes according to the sizes marked on the accompanying drawings. Clear the holes of all burrs and clean the panel down with either steel wool or a weak caustic solution. You can then paint the panel and when the paint is thoroughly dry it can be carefully lettered. We used white Letraset on the black panel. A spray-on lacquer will protect the lettering. Once the panel is prepared, fit the switches and the handles. The latter were made from pieces of aluminium channel, also sprayed black. Handles aren't essential, but they can be handy.

Next, mark out and drill the three rear panel pieces. Short lengths of 75 mm (3") channel were used to secure these to the front panel. You can do a 'trial' assembly using the unassembled pc boards to mark their mounting hole positions. If you drill holes a little oversize then you have some latitude for adjustment later to allow for inaccurate marking or drilling. The mechanical assembly drawings should assist you here.

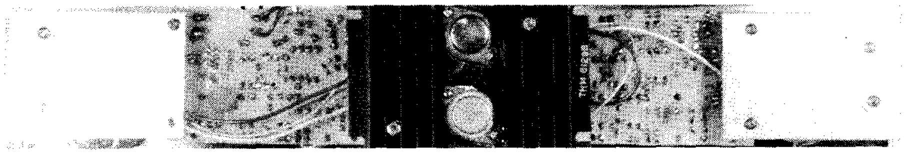
Having got the rear panel pieces sorted out, you can decide where to mount potentiometers RV2 and RV4 (the S/C and MAX. SET pots). You may elect to mount them directly on the front panel or glue them to the rear panel, as we did. We used Silastic to glue them in place. The shaft ends of the two pots were grooved with a hacksaw cut so that they could be adjusted with a screwdriver. Make sure the pot shafts line up with the panel holes. The two relays were secured to the channel pieces at either end of the panel using Silastic. You can mount all the switches and the throttle pots now. That's it for the moment with the mechanical assembly, now you can get on with the pc boards.

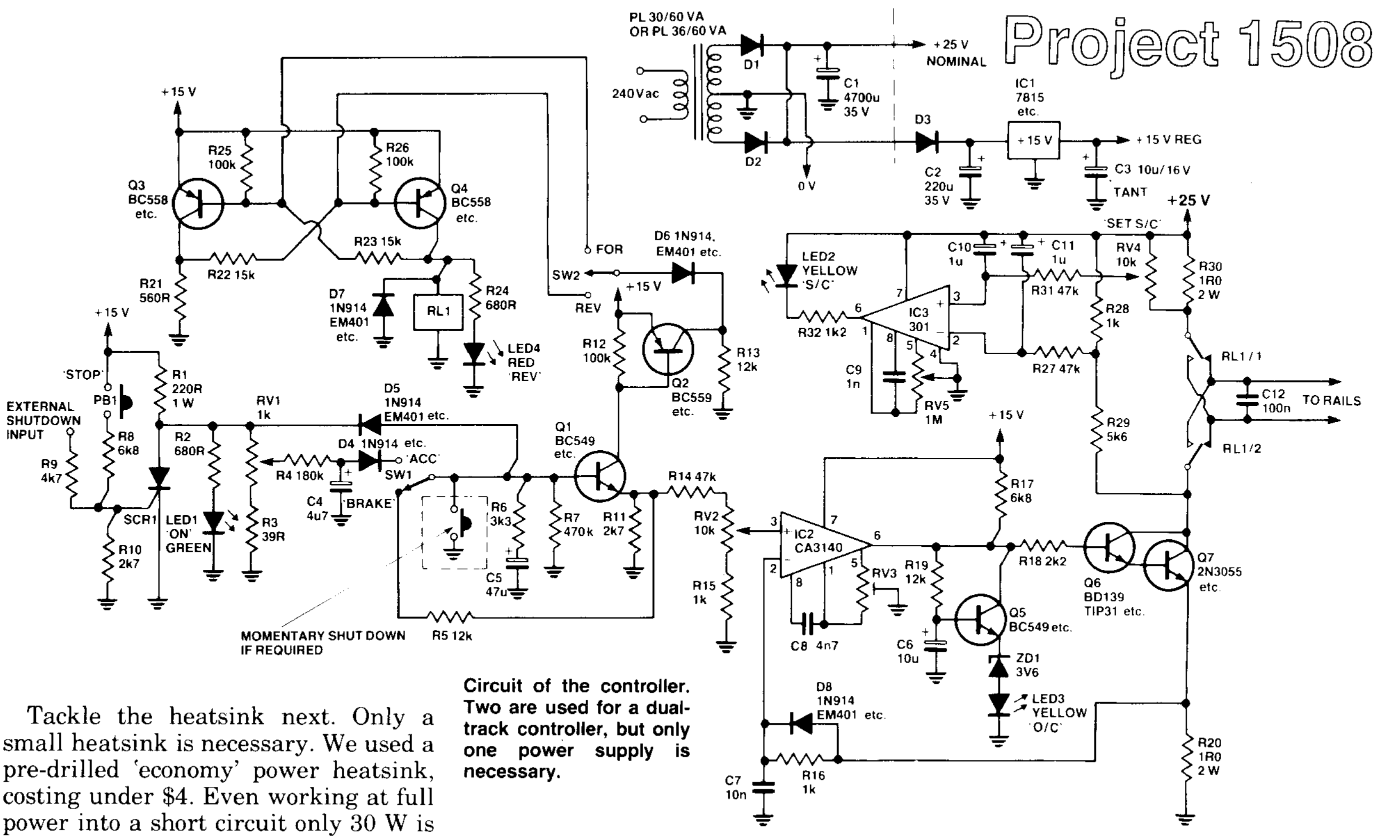
We have drawn up a component overlay and wiring diagram to assist assembling and wiring the pc board. Follow the component overlay for mounting the components to the pc board. Start by soldering the resistors and non-polarised capacitors (i.e: not the electrolytics) in place. Then follow with the polarised capacitors, making sure you get them in the right way round. A small '+' is on the overlay diagram where the positive lead is to be inserted. Identify the leads from the accompanying component pinout diagram. Solder all the semiconductors in place next, taking care you get all of them the right way round, too. You can identify which way they go from the overlay and pinout diagrams. Note that low power types for IC1 and SCR1 can be used, rather than the 'flatpack' higher power versions illustrated on the overlay. The low power versions come in transistor-type plastic packages with just three flying leads and no metal tab.

If you're using the flatpack types, we recommend that you bolt them to the pc board.

When you have fitted all the components to the pc board, make a careful check that all components are correct and those that need to be are correctly orientated. If all is well, you can now attach all the flying leads. Make sure each is of adequate length to reach from the pc board to their intended destination with some to spare.

Rear view of the controller.





Circuit of the controller. Two are used for a dual-track controller, but only one power supply is necessary.

Tackle the heatsink next. Only a small heatsink is necessary. We used a pre-drilled 'economy' power heatsink, costing under $4. Even working at full power into a short circuit only 30 W is dissipated. Mount the 2N3055s and BD139s to the heatsink taking care to insulate the 2N3055 with a mica washer. Ensure that no burrs on any of the holes can puncture the insulator. Smear the insulator both sides with thermal compound before mounting it. Check with an ohmmeter that none of the transistor leads is shorted to the heatsink. ▶

HOW IT WORKS — ETI-1508

The circuit of the train controller can be considered as five separate functional blocks: power supply, current control, current regulator, reversing control and short circuit detector.

The current control serves to interpret the driver's instructions and, taking inertia and energy into account, outputs a voltage proportional to the requisite engine torque. The current regulator forces the train to conduct this current and indicates the high resistance, or open circuit, condition, should it occur. The reversing control consists of a flip-flop driving a relay. This circuit will only toggle when the train is not being driven, preventing reversal during operation. Finally, the short circuit detector continuously searches for a low resistance condition in the load.

The power supply requirements are: a 15 V regulated rail for the electronics and an unregulated rail of between 18 and 35 volts. The circuit can tolerate severe ripple on the unregulated supply. Its only constraints are that the average voltage should lie between 18 and 30 volts with peak excursions no more than 35 volts and minimum excursions no lower than 10 volts. The supply must be able to deliver at least 1.5 amps per controller. We recommend a transformer such as the Ferguson PL36/60 VA or PL30/60 VA, which should be more than sufficient for two controllers. The +15 V rail is separately regulated for each controller, the regulator IC being mounted on the pc board (IC1). Diode D3 isolates C2 and IC1 from severe ripple on C1. IC1 may be a low power type (78L15) but provision for a 7815 was made on the pc board as these are more readily obtainable. Capacitor C3 bypasses the +15 V rail and prevents IC1 oscillating.

The current control comprises SCR1, SW1, RV1, Q1 and surrounding components (i.e: about the middle of the circuit!). If about 4 — 15 V appear on the 'EXTERNAL SHUTDOWN' input, or the 'STOP' button is pressed, SCR1 is triggered, removing drive from RV1 and discharging C5 via D5-R6. This condition is indicated by LED1 going out.

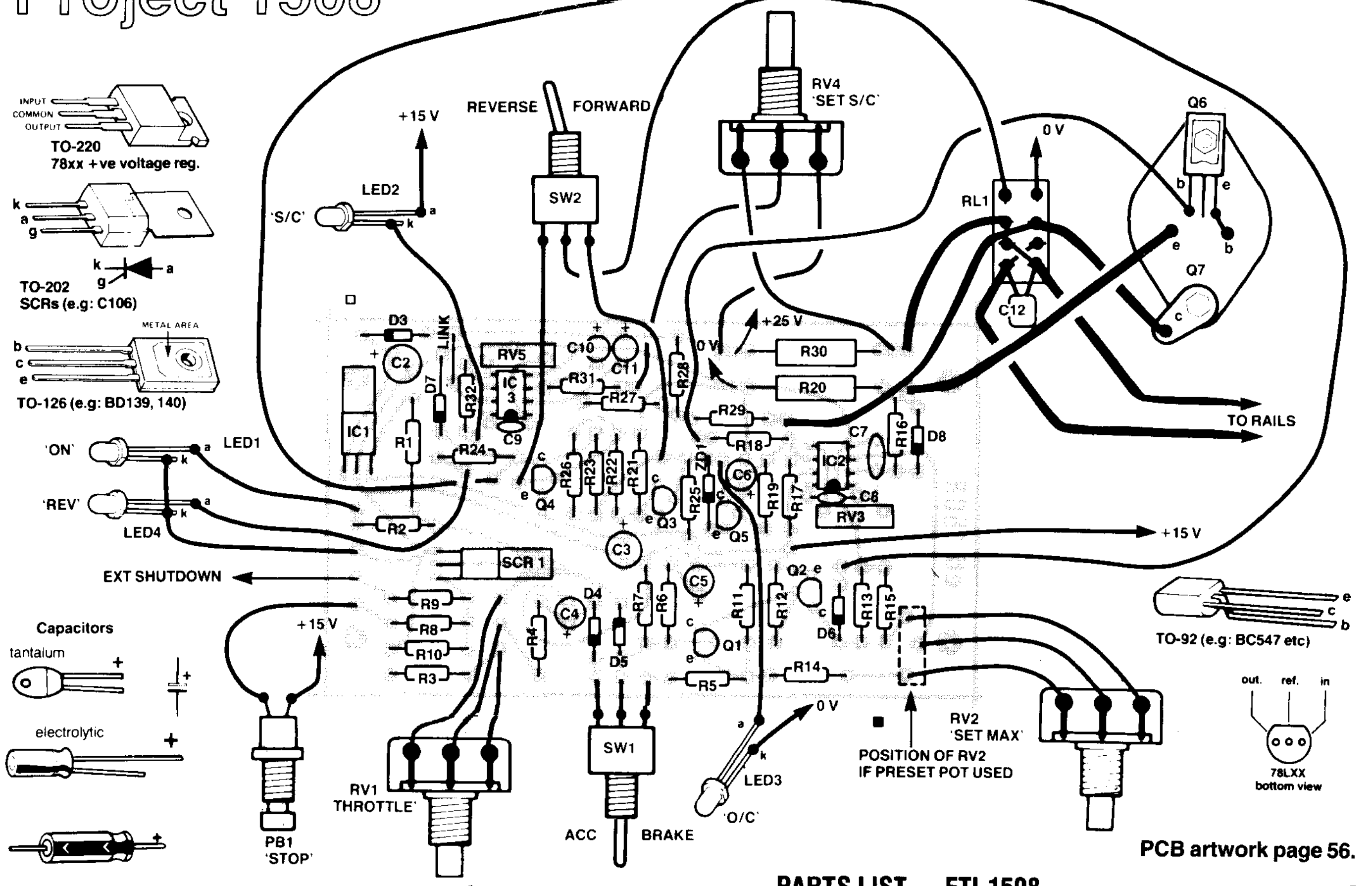
Normally, when SCR1 is not triggered, control is vested in SW1 ('ACCELERATE — BRAKE') and RV1 ('THROTTLE'). With SW1 in the mid (open) position, C5 remains discharged while C4 charges to the level set by RV1. When SW1 is moved to the ACCELERATE position, C4 discharges into C5 via R6. This causes C5 to charge to about 20% of the final voltage set by RV1. Also, a small voltage pulse appears on the base of Q1. Capacitor C5 then charges exponentially via R4 to the final level. If RV1 is reduced, D4 prevents C5 discharging through R4. Capacitor C5 discharges via R7, allowing a different rate of reduction of speed, as is the case in reality. (A train accelerates faster than it slows down if no braking is applied).

If SW1 is placed in the 'BRAKE' position, a constant current is drawn out of C5 via R6 and R5, because Q1 maintains its emitter voltage at about 0.65 V below its base. This action causes a linear reduction (rather than an exponential fall-off) of the voltage on C5. (A vehicle dissipates energy proportional to the square of speed. This linear braking effect causes the model to reflect this sharp-halt situation more realistically). Transistor Q1, acting as an emitter follower, copies this voltage on C5 out to RV2 via R14. Thus, the initial peak and the continuously varying voltage on C5 are output for the current regulator.

The current regulator consists of IC2 (a CA3140) and surrounding components. This is simply an op-amp wired to ensure that the emitter current of Q7 in amps equals the voltage on pin 3 (the non-inverting input). Trimpot RV3 is included so that a small offset voltage may be established to fix the emitter current of Q7 at a value of about 15 mA when the voltage on pin 3 of IC2 is at 0 V. This minimum current value allows the short circuit and open circuit detectors to work all the time, even when the train is stationary. This current is not sufficient to cause train movement. Resistor R16 and capacitor C7 remove hash caused by commutation and dirt on the tracks. Diode D8 is required to protect the circuit from overload when going from an open circuit condition to a short circuit condition. Transistor Q5 and surrounding components detect the open circuit condition. If the collectors of Q6-Q7 go open (i.e: no current supplied via the rails), they saturate, the voltage on R20 falls and the output of IC2 rises toward the +15 V rail. If this condition persists for more than quarter of a second or so, C6 charges up and Q5 turns on LED3 via ZD1. The delay prevents flickering due to momentary effects such as crossing isolators on the track or dirty engine pickup wheels.

Reversing is achieved by operating the relay, RL1. Transistors Q3 and Q4 form a flip-flop which drives RL1 on in one state and off in the other. When Q1 draws no current (i.e: there is no drive signals to IC2) Q2 is off, allowing SW2 to toggle the flip-flop by pulling the base of either Q3 or Q4 to ground via D6-R13. When running the train, Q2 remains turned on and SW2 has no effect because of D6. The 'REVERSE' indicator, LED4, lights when Q4 is on and the relay activated.

The short circuit detector is built around IC3. This acts as a comparator. Its output lights LED2 if the voltage across the relay contacts drops below a preset ratio of that voltage dropped across R30, the current sense resistor. Capacitors C10 and C11 prevent IC3 responding to hash. Trimpot RV5 is for nulling the op-amp offset. Capacitor C12 also helps reduce interference from getting into the high gain circuits on the pc board.



PCB artwork page 56.

You can wire up the transistors and attach flying leads, referring to the wiring diagram, but don't connect the leads from the pc board yet.

Now you can return to the mechanical assembly. Mount the pc boards and wire up all the flying leads. Note that the +15 V and 0 V leads go to several locations each: for example, LEDs 1, 3 and 4 all have their cathodes (k) going to 0 V. Double check to see that no connections to off-board components are left unused. We used double-pole switches for SW1, SW2 and PB1. This was mainly because single-pole versions were not available at the time we constructed the prototype. The spare poles were unused.

Note that heavier gauge hookup wire should be used to connect the collector and emitter of Q7 to the rest of the circuit. Use 24 x 0.2 mm plastic insulated hookup wire at least.

Now check *everything.*

Finally, wire up the rectifier and filter capacitor as per the wiring diagram, unless you're using some other supply, and connect up the power transformer. Take care with the mains wiring. If you are using an existing transformer/rectifier, then only a filter capacitor is needed. Its value depends on the voltage: we recommend at least 3300 uF for a supply of 21 volts peak, which is the minimum unsmoothed supply recommended. Now you're ready for 'the big switch on!'.

PARTS LIST — ETI-1508

Resistors	all ½ W, 5% unless noted
R1	220R, 1 W
R2, R24	680R
R3	39R
R4	180k
R5, 13, 19	12k
R6	3k3
R7	470k
R8, 17	6k8
R9	4k7
R10, 11	2k7
R12, 25, 26	100k
R14, 27, 31	47k
R15, 16, 28	1k
R18	2k2
R20, 30	1R, 2 W
R21	560R
R22, 23	15k
R29	5k6
R32	1k2
RV1	1k lin. pot.
RV2	10k trimpot or lin. pot
RV3	10k trimpot
RV4	10k pot.
RV5	1M trimpot

Capacitors

C1	4700u/35 V or 50 V axial electro.
C2	220u/35 V RB electro.
C3, 6	10u/16 V tant.
C4	4u7/16 V RB electro.
C5	47u/16 V RB electro.
C7	10n greencap
C8	4n7 greencap
C9	1n greencap
C10, 11	1u/16 V tant.
C12	100n greencap

Semiconductors

D1-D3	1N4001, EM401, 1N4002 etc.
D4-D8	1N914, 1N4148, 1N4001 etc.
IC1	7815, 78L15
IC2	CA3140
IC3	LM301, uA301
Q1, Q5	BC549
Q2	BC559
Q3, Q4	BC558
Q6	BD139, TIP31
Q7	2N3055
LED1	TIL220G green LED
LED2, 3	TIL220Y yellow LED
LED4	TIL220R red LED
SCR1	C106

Miscellaneous

RL1	12 V double-pole change-over relay with contacts rated at 2 A or more, coil 240 ohms or more.
SW1	SPDT toggle switch with spring return.
SW2	single-pole, three-position switch, centre-off, spring-loaded return one side.

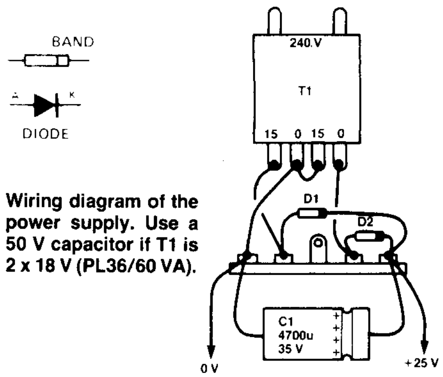
ETI-1508 pc board; PL30/60VA transformer or PL36/60VA, if needed; knobs to suit; panel metalwork, channels etc as per drawings; spacers; nuts, bolts etc; hookup wire.

Note: For a twin-track controller, two of everything except the mechanical hardware will be necessary.

Price estimate $105 — $115 (dual track unit)

Adjustments

Once the wiring up is complete some adjustment of preset pots must be made. As well, some adjustment of component values may be desirable in order to tailor the controller action, or 'feel', to your particular requirements. You may also wish to modify the action of the 'STOP' button.



Wiring diagram of the power supply. Use a 50 V capacitor if T1 is 2 x 18 V (PL36/60 VA).

TABLE 1

Possible component variations.

FUNCTION	COMPONENT TO CHANGE	RANGE OF VALUES
Acceleration	R4	50k to 330k
Starting pulse magnitude	R6	100R to 10k
Slowing	R7	390k to 10M
Braking	R5	1k to 27k
	(Note: R4 affects this too!)	
% charge jump	C4	0 to 20 uF

*Do not forget to adjust R14 if necessary to limit maximum current to 1.5 A.

There are two preset potentiometers, the offset null pots for the two op-amps, which must be adjusted. These will probably never need readjustment once initially set. The 3140 (IC2) offset pot should be adjusted to give the required 15 mA minimum current in the output. Place a current meter across the track, and adjust this pot until 12 to 18 mA flows. Removing the meter, leaving an open circuit, should illuminate the O/C LED. Shorting the output will turn it off.

The 301 (IC3) offset pot should be adjusted with pins 2 and 3 shorted to pin 7. When you have temporarily made these connections, move the wiper to and fro, observing that one direction turns the S/C LED off, the other turns it on. Leave the wiper at the point of switching just so that the slightest movement in the appropriate direction will toggle the LED. Remove the temporary connection. Verify the correct connection and operation of the short circuit detector by following this procedure: place a locomotive on the track; adjust the 'SET S/C' pot, slowly, until the LED just goes out. If the track is now shorted, the LED should come on. This takes half a second or so. The SET pot can be adjusted to recognise any resistance from almost zero to 5 ohms at least, as the minimum acceptable value, before a short condition is indicated. This range will be adequate for all normal wiring up resistances, etc. The 'SET MAX' pot is adjusted simply to set the level which is the most current a locomotive or pair of locomotives will ever need. It can be adjusted either with a current meter if you know the value, or simply to give convenient feel to the throttle knob. If you find you are always at the beginning of the throttle range, adjust this pot down to reduce the maximum. If you always need full throttle to run a train, adjust it up.

Once you have familiarised yourself with the operation, you may wish to change certain time constants. The accompanying table shows what components affect what characteristics. Recommended values fit recent design HO scale models. If you wished to increase all the time constants because your layout is very large, you could increase C5, or vice versa. This will also affect the initial current jump, reducing it. If you need to restore this or even make it larger, increase C4 as well. If you change any of the resistors, you may need to change R14. This resistor does not directly affect the 'feel' of the controller, but limits the maximum current which may be requested, to the controller limit of 1.5 A so that prolonged short circuits at full current cannot harm the unit. It is likely that R4, C4 and C5 only will need changing, to tailor the controller for another scale, such as N-gauge, etc.

Finally, you may wish to change the STOP button action. We suggest wiring it as shown in the diagrams. It triggers the SCR when pressed. This locks out the controller until the SCR is isolated by turning off the supply. Two modifications may be implemented. Firstly, you may wish to have it stop the trian but allow it to start as soon as the button is released. This is achieved by wiring it from the top of R6 to ground. Alternately you may wire it across the SCR, anode to cathode. This has the advantage that it may be used to restore power by isolating the SCR if it is triggered by an external signal. The other option is to include a separate (possibly concealed) button across the SCR for restoring power. Whichever option you wish is open to you. We feel that the need to use the button should incur some inconvenience, so we opted for the turn-off-to-restore-power method.

The external SCR trigger input is provided for those who wish to include some logic in their layout. Position sensors, point and signal control systems, etc, may be wired to stop the train by means of applying a TTL-high (4 V or more) to this input, which has the effect of pressing the STOP button. ●

Some Notes on TRAIN DRIVING and Problems you may encounter

This controller, as we have said before, delivers constant current rather than constant voltage. Constant current produces constant motor torque. Thus, just as is the case in a car, the train will slow for hills, speed up for descents, etc. This will mean that you have to pay fairly constant attention or the train will end up derailing or throwing carriages due to speed or 'stalling' due to insufficient 'gas'. The author can barely manage to control two trains at once, so be warned that train driving is not as easy as it used to be! Braking is also not exponential, as is acceleration. This corresponds to an effect you may have noticed if you drive a car — hard braking at 25 kph causes fairly severe loss of speed, but hard braking at 125 kph causes an alarmingly mild reduction of speed; you dissipate energy proportional to speed, but the energy needed to be dissipated rises with the square of speed.

A problem which demands some discussion is that of 'starting torque'. Many model engines, particularly old ones (the author has several engines over twenty years of age) have a tendency to require an amount of current to start moving which is greatly in excess of that to keep moving. Thus they sit still until the 'starting torque' is achieved then take off at some speed. This is not due to bad contacts. To some degree this controller scheme can overcome the problem. Firstly, actual bad contact problems will be automatically resisted, and indication is given as soon as the fault becomes serious. Thus, these will be separated from other problems and can be remedied by cleaning, and so forth. Secondly, the controller gives a small 'jerk' at startup, corresponding to the takeup of coupling slack in a real train. If controls are adjusted suitably, the train will not quite stop after this jerk (which should easily exceed starting torque) and will pull away smoothly. Recall that the controller output jumps to some preset fraction of the initial throttle setting immediately after switching to the 'accelerate' position of the main control switch. Judicious adjustment of the throttle before startup can ensure a sizeable jerk and a large initial step level. If necessary, increasing the startup capacitor C4 will increase the initial step torque so that the engine does not come to rest even for a moment after startup. Reducing R6 will reduce the duration of the jerk, increased by increasing C4. Newer engines respond smoothly and may benefit purely from reduction of R6 to minimise the startup jerk. Our older engines used 15 uF for C4 successfully.

One further point arising is that the jerk may be reduced or eliminated where you wish by reducing the throttle to zero before going to accelerate mode, and bringing it up as soon as you start up, though this eliminates the initial torque step. Our prototype units delivered a typical jerk of about 30 degrees of wheel rotation on a model steam locomotive — most pleasing.

Another problem which is regretably unique to current type controllers such as this one is that they do not like the non-linear load of incandescent lamps in parallel with the engines. Two effects will be evident: when the train is stationary, the lamps are cold and look like a short circuit and so the S/C detector will respond. It will reset as soon as power is delivered however, and should be sensitive enough to be settable at the level where only a genuine short is registered. The second problem is that the cold lamps draw a lot of the current delivered in total until they heat up and begin to glow, whereupon they allow a much larger voltage across themselves while drawing the same current. This makes the train sluggish at first and likely to run away once the lamps are on. This effect is similar to and worsens the starting torque problem. In general, lamps should be avoided or at least have a few tens of ohms inserted in series to minimise the problem. Using lower voltage units and series resistances is less power economical but better. The author uses LEDs on locomotives, which are sufficient and do not affect performance.

Model railway points controller and indicators

This project employs a capacitive discharge type power supply to drive the solenoid actuators in model railway points switchers. An add-on indicator unit can be used in conjunction with it to show which way points are switched at any time.

Jonathan Scott

THE IDEA of using a capacitive discharge supply to drive the solenoids in model railway points switchers is not new. Indeed, you can buy these at hobby shops for $20 or so, if you are not inclined to build one for yourself. However, this project incorporates refinements you may not have seen, along with a system of indicating the state of the points modelled after the fashion of the 'professional' signal box lighted map.

The capacitive discharge supplies bought 'over the counter' generally charge a capacitor of one to two thousand microfarads via a current limiting resistor from a rectifier and an ac source. This is quite adequate, but can be refined. If you charge the capacitor from a constant current source, it charges somewhat faster and one can provide an 'unready' indication while it's charging. The little extra speed one gains in charging is handy as several points often need to be changed in a short space of time and one's fingers dance from button to button when doing so.

With either system, the current limiting arrangement protects the solenoids against burnout if the supply happens to be accidentally connected indefinitely. The simpler system almost invariably incinerates something if you get a short somewhere.

The idea behind the capacitive discharge method is simply that the point changes in the first hundred milliseconds or so, any other power delivered is wasted. The high momentary current capability of a capacitor means that the solenoid always moves quickly. When you connect the charged capacitor to the points solenoid it will deliver a very high current which rapidly subsides to nothing or, at worst, the charge current which can be much less than the current required to actuate the solenoid. Thus, the solenoid remains cool even if connected (by some accident or other) indefinitely, avoiding burnout of the solenoid.

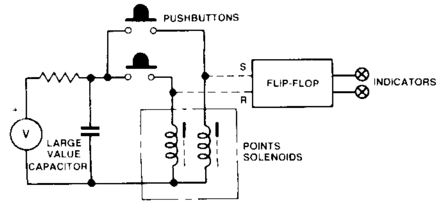
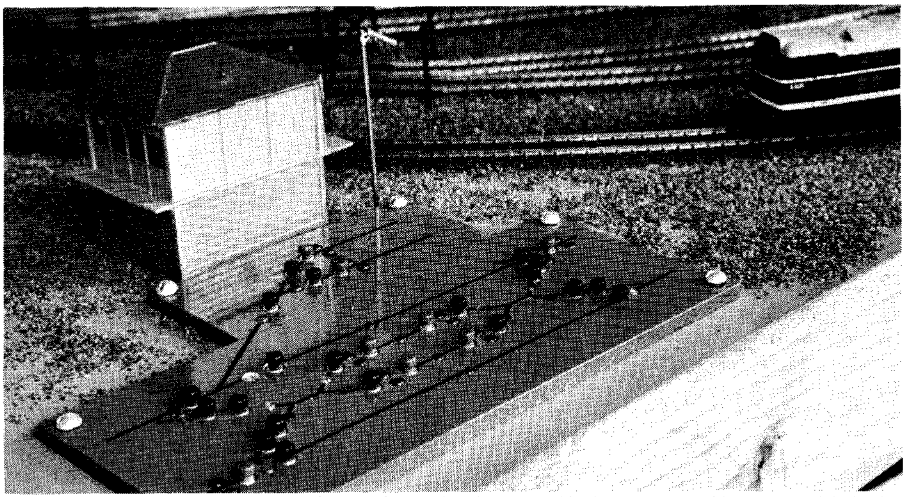


Figure 1. The controller/indicators scheme.



Signal map. This shows a view of one of my signal maps with the points pushbuttons and indicator LEDs installed.

The outline of a capacitive discharge supply is shown in Figure 1, along with the outline of a 'remote point indicator', or 'remoter'.

The remoter is simply a 'memory' circuit which records which way the point was last changed. I used a simple flip-flop for this. Two LEDs or lamps are used to indicate the point's condition. These may be built into a signal map panel. This is basically just a line diagram of a track layout, or part thereof, with lights and switches in the symbolic positions of the actual points on the track layout. Train signal lights are also usually included on the map along with train position sensors, if used.

There is, of course, no need to have remoters. They are purely conveniences, rather than necessary functional items. Remoters are primarily important if you wish to have a layout which is as much like the 'real' thing as possible. However, for the few dollars or so extra cost each, they add a very pleasing touch of realism.

You can have any number of points in your layout and you'll only need one capacitive discharge supply unit. The one described can easily drive three points simultaneously if you need to operate some points together. One remoter is needed for each set of points.

Construction

Construction is relatively brief. The only part we can really cover here is the assembly of the pc boards and with the usual exhortation "assemble the boards according to the overlays", it's nearly all over!

There are two pc boards: ETI-1510a is the capacitive discharge supply, and ETI-1510b is for the remoters. Let us take the supply board first. It is easiest to mount the diodes and resistors first, then Q1 and IC1, followed by the capacitors. Take care with the orientation of the diodes and transistors as well as C1 and C2. Note that Q1 and IC1 should have heatsinks attached. You can make these from a scrap of aluminium; each heatsink should be at least 25 sq. cm in area. They can be bolted straight to the metal face of each device, but don't forget to smear on thermal compound first.

You may or may not wish to mount the 'charging' LED (LED1 on ETI-1510a) off the

PARTS LIST — ETI-1510a

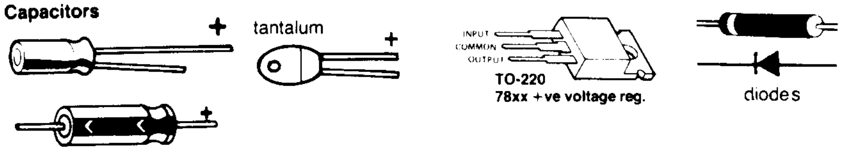
Resistors	all ½ W, 5%
R1	2R7
R2	1k2
Capacitors	
C1	1000u/25 V RB electro.
C2	3300u/25 V axial electro.
C3	10u/6 V tant.
Semiconductors	
D1-D6	1N4001/2/3/4 etc
LED1	TIL220R red LED
IC1	7805
Q1	BD140
Miscellaneous	
ETI-1510a pc board; hookup wire, etc.	

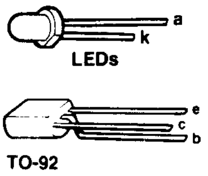
Price estimate $8 — $10

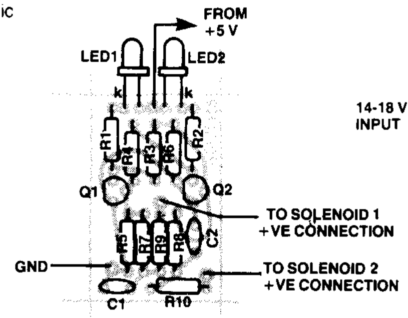
PARTS LIST — ETI-1510b

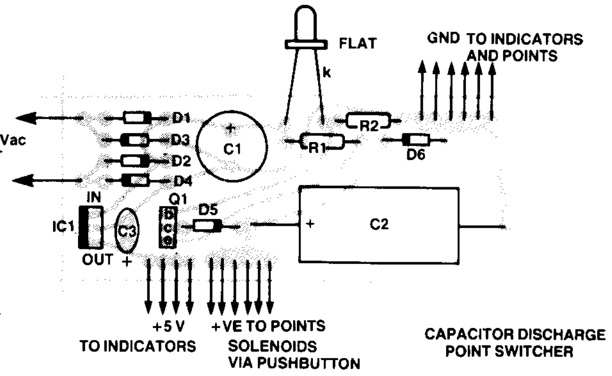
Resistors	
R1, R2	see text, circuit
R3, R4	see text, circuit
R5, R6	100k
R7, 8, 9, 10	47k
Capacitors	
C1, C2	100n greencap
Semiconductors	
LED1	TIL220Y yellow LED
LED2	TIL220G green LED
Q1, Q2	BC549
Miscellaneous	
ETI-1510b pc board; hookup wire, etc.	

Price estimate $4 — $5

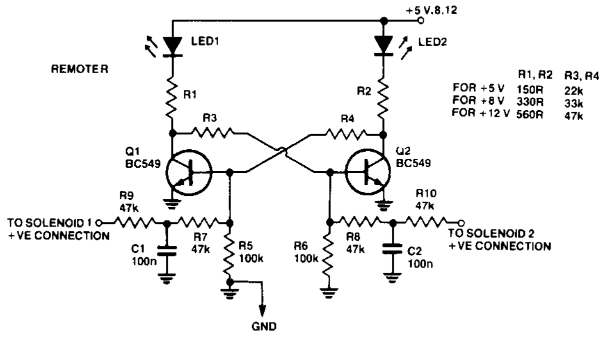


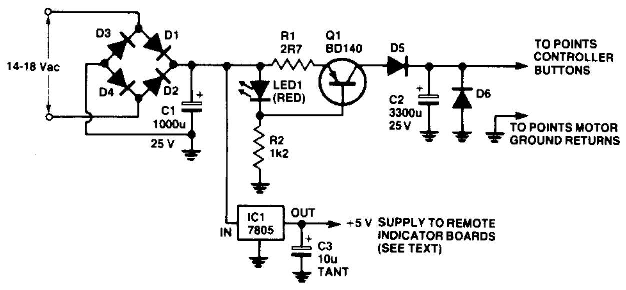






CAPACITOR DISCHARGE POINT SWITCHER




14-18 Vac
D3
D1
D4
D2
C1 1000u 25 V
R1 2R7
Q1 BD140
D5
LED1 (RED)
R2 1k2
C2 3300u 25 V
D6
TO POINTS CONTROLLER BUTTONS
TO POINTS MOTOR GROUND RETURNS
IN
IC1 7805
OUT
+5 V SUPPLY TO REMOTE INDICATOR BOARDS (SEE TEXT)
C3 10u TANT

MORE TANTALUMS WILL BE NEEDED IF WIRES ARE LONG. THEY SHOULD BE MOUNTED AT THE REMOTERS

HOW IT WORKS — ETI-1510

There are two distinct parts to the project: the first is a capacitor discharge supply used to operate the point solenoids, the second is a remote indicator unit.

The capacitor discharge supply unit charges a capacitor which is then discharged into the point solenoid, which then operates the points. This unit is capable of changing one point every half second or so, and can power a large number of points together.

The remote indicator unit, or 'remoter', has the job of 'remembering' which way the point set was last switched and indicates the direction with a pair of LEDs mounted as part of a signal map.

Consider the capacitor discharge unit. Diodes D1-D4 rectify the 14-18 volt ac input to provide a dc supply. Capacitor C1 smooths this for IC1 which regulates the voltage supply for the remoters. Up to fifteen remoters can be run off the output of IC1.

Transistor Q1 and surrounding components form a current source which charges C2 via D5. LED1 forms the voltage reference and doubles as an indicator which illuminates for the time when the capacitor is being recharged after use. Diode D5 prevents reverse biasing of the transistor when C2 is charged and C1 is below the peak input voltage value.

Using a current source for the charging element removes the need for a large series resistor and speeds up recharging as well as making the system short circuit proof.

Diode D6 is a "freewheel" diode which prevents possible reversing of the polarisation of C2 by the flyback voltage of a solenoid.

When a button is pressed, making a connection from the output of the unit to a point solenoid, C2 discharges into the coil, changing the point. After C2 is discharged the only current flowing through the coil is the recharge current of about 375 mA. When the button isolates the point solenoid, the current is free to charge C2, which takes about quarter of a second. When C2 reaches the input voltage, Q1 saturates, LED1 goes out, and the unit is ready to operate again.

The 375 mA charging current is insufficient to harm a solenoid if it is left connected for any reason. As the controller can withstand indefinite shorting itself, the whole system is protected against abuse and failure of switches, etc.

Each remoter consists of an R/S type flip-flop formed by two transistors. Assume initially that Q1 is on, and Q2 off. The collector current of Q1, via R1, illuminates LED1, and the saturation collector voltage of Q1 ensures that Q2 remains off.

When a solenoid is activated by the discharge of the capacitor, a large voltage spike appears across it. Suppose that the voltage across the coil appears on R10. Capacitor C2 filters out brief induced spikes, so that no signal other than the correct one can affect the circuit. When the longer duration discharge pulse appears on R10 some current reaches the base of Q2, turning it on. This turns on LED2 via R2 and removes the base drive from Q1, and it turns off. Thus LED1 goes out, and the collector voltage on Q1 keeps Q2 turned on via R3. The reverse operation occurs when a pulse appears on R9.

Transistors are used rather than an IC as they have a higher output drive, are less intolerant of supply voltages and ICs normally have more than one flip-flop in each package and you waste the rest.

board; like on the front panel of your controller, for example. This is a good idea if other people are using your layout as it helps them allow for the necessary delay between point switching operations of about half a second or so. Make sure you wire in LED1 the right way round.

The remoter board (ETI1-1510b) is quite straightforward. Best way to tackle this one is to mount the resistors and capacitors first. Then mount the two transistors making sure you get them the right way round. Finally, mount the two LEDs. Leave their leads long as the board can actually 'hang' from them. Alternatively, the LEDs may be mounted off the board and the board mounted somewhere conveniently nearby.

I secured my boards to the underside of the model railway baseboard with staples from a staple gun holding down the wires to and from the units. The capacitive discharge supply was actually mounted at right angles to the baseboard. The remoters were held flat on the baseboard by stapling the wires fairly close to the pc board. This arrangement has proved entirely satisfactory.

Trying out

The ETI-1510a board (supply) can be tried out first. Hook up the input to an ac source of between 14 and 18 volts. On switch-on, LED1 should light then extinguish about a second later. If not, check that it's connected the right way round. If that's OK, check that you're getting about 1½ times the ac input voltage across C1 (between 20 and 25 Vdc or so should appear across it). If not, switch off and check that diodes D1 to D4 are all correctly oriented. Correct any faults as you go. When you've got LED1 to light on switch-on, then check that the output of IC1 is +5 V. Measure the voltage across C2. It should be equal, or nearly so, to the voltage on Q1. If LED1 won't go out, or there's less than one volt aross C2, odds-on you've got D6 the wrong way round.

Temporarily hook up the supply to a points solenoid and see that it operates as expected.

You can check out the remoter(s) by temporarily connecting it to the +5 V from the supply board. One or other of the LEDs will light. Say LED2 on the remoter lights. Connect the 'SOLENOID 1' input momentarily to the positive terminal of C2 on the supply. LED1 should light and LED2 should extinguish. If not, check transistor and LED orientations. If this works, then temporarily connect the 'SOLENOID 2' input to the positive terminal of C2 and the LEDs should swap over.

When wiring in the remoters, it may be necessary to add some extra supply bypassing to prevent random toggling of the LED indicators. Add a tantalum with a value between 4u7 and 10u. You'll need one of these per extra metre of cable length if the cable is a metre long or longer.

Wiring multiple points

Invariably, you will want to install multiple sets of points, some of which operate alone, some of which may need to operate together. There are two wiring options which exist and which may prove useful if you have not seen them before.

It often happens that two points will always need to be switched together. These can be wired directly in parallel and operated by only two pushbuttons. The capacitive discharge supply described should drive such an arrangement easily, without the need to increase the value of the discharge capacitor (C2 on ETI-1510a). The 3300u capacitor specified would easily and reliably operate three parallel points in my layout. If you need to drive more, then the capacitor's value can be increased (try 4700u). Conversely, you can decrease the capacitor's value if you find your solenoids are light ones and/or don't have parallel operated points. Don't forget that, if you increase the capacitor's value, you'll increase the charging time. If you decrease it, charging time speeds up.

Sometimes there is a need to have one set of points 'slaved' from another, but have the first set operated independently also. This is readily achieved by the inclusion of some simple diode logic. A diode with its anode connected to one solenoid and its cathode connected to another will leave the first point unaffected by the second when switched, but will ensure that when the first is switched, the second also operates. This can be implemented with ordinary silicon rectifier diodes such as EM401s, 1N4001s, etc.

The various wiring arrangements are illustrated in Figure 2.

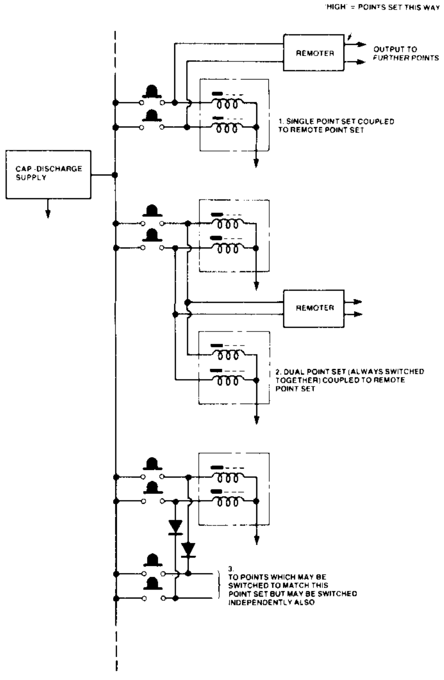

'HIGH' = POINTS SET THIS WAY
REMOTER
OUTPUT TO FURTHER POINTS
1. SINGLE POINT SET COUPLED TO REMOTE POINT SET
CAP.-DISCHARGE SUPPLY
REMOTER
2. DUAL POINT SET (ALWAYS SWITCHED TOGETHER) COUPLED TO REMOTE POINT SET
3. TO POINTS WHICH MAY BE SWITCHED TO MATCH THIS POINT SET BUT MAY BE SWITCHED INDEPENDENTLY ALSO

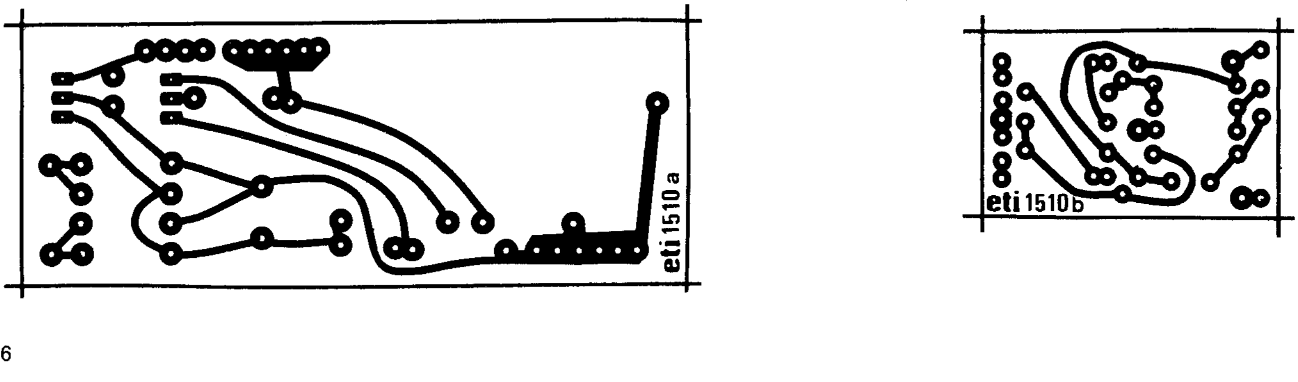
Figure 2. Showing the three fundamental schemes for wiring points.

Logic output

One advantage of remoters is that they can output the state of a point set as logic levels for feeding into a digital system or computer. Astute readers will have noticed a certain provision in these model railway projects for a computer interface. The collectors of the transistors in each remoter circuit give a 'low' voltage when the respective side is that one carrying the traffic. For a 5 V supply, the levels are TTL. This is the main reason that the remoters are run from a carefully regulated supply, apart from a desire to keep LED illumination level fairly constant. For those needing CMOS or other levels the resistor values for 8 V and 12 V supplies are shown on the diagrams. (R1-2 and R3-4 will vary.)

Coupled with position sensing systems, the remoters can allow a simple anticrash logic system to be hardware implemented!

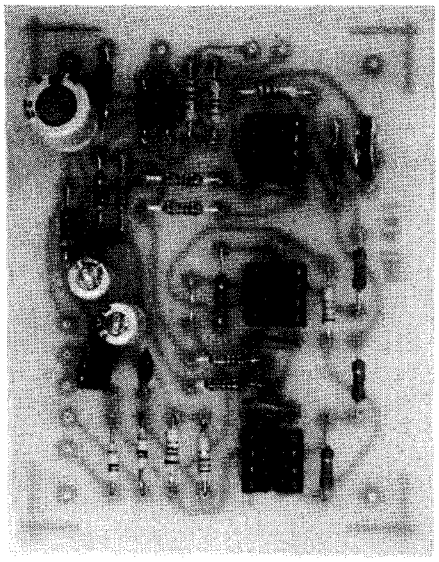
Printed circuits. Full size artwork of the two pc boards.



Project 461

Balanced input differential preamp

David Tilbrook



This versatile little preamp has a host of applications in the audio-and-beyond range, not the least of which would be as a balanced mic preamp.

MANY transducers require a balanced or differential preamplifier rather than the simpler single input unbalanced type. Balanced microphones, for example, require a balanced preamplifier to ensure minimal susceptibility to extraneous noise sources. The concept in the balanced approach is fairly simple. The microphone, for example, is connected to the balanced preamp using three wires instead of two. Two of these wires carry signal and the other is a ground connection. The balanced source, in this case a microphone, generates a signal voltage on the two signal wires such that one of the signals is 180 degrees out of phase with the other. The two active lines are twisted together, with the earth line, or a two-wire shielded cable is used to connect the mic to the preamplifier. In this way any external noise or hum source will affect both inputs equally, producing a signal that is in phase on both of the signal wires. Such a signal is called a *common mode* signal. The balanced preamplifier however, is configured in such a way as to amplify only a differential signal. The preamp produces an output signal that is proportional to the difference between its two inputs. Since the signal is generated out of phase, it is amplified. The noise source however is a common signal and is the same in both input wires. The difference between the noise signals on each of the input wires is therefore zero, and is not amplified (see Figure 1). With this technique small signals can be sent over long lines, an otherwise impossible task due to the susceptibility of these lines to mains hum in particular.

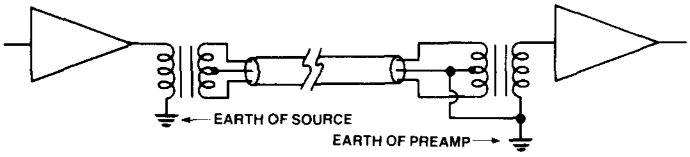


Figure 2. **Balanced line with transformer coupling.**

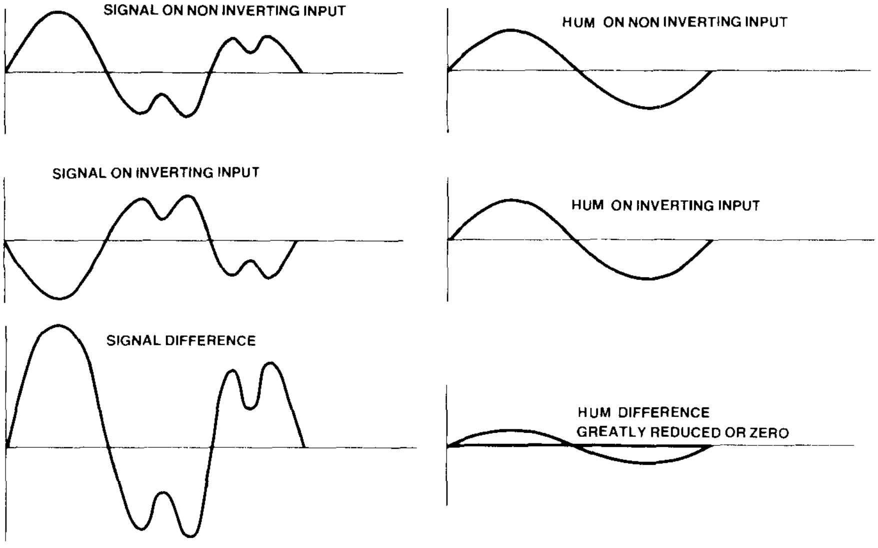


Figure 1. **Differential signals on a balanced line are amplified while common-mode signals are reduced.**

In audio the most common method employed to implement a balanced line is with transformers. The basic approach is shown in Figure 2. The source may be a microphone or a small preamplifier inside the microphone, or simply the output from a mixer or other electronic device. This is connected to the input of a balancing transformer that is wound to represent the correct load to the driving stage. The output of this transformer consists usually of a bifilar wound secondary connected as shown in Figure 2. A similar transformer is used at the other end of the line to convert the differential signal back into one that can be amplified by the single input preamp. This technique has the advantage that the signal earth of the source need not be connected to that of the preamplifier. This can be a *very* useful feature at times, particularly when large numbers of cables are connected together at a common point such as at a mixing console. The ability to isolate the input earths of the various inputs enables complete freedom from hum loops which otherwise can become almost impossible to remove.

Transformers have disadvantages however. Firstly, good ones are expensive as they must be carefully wound and shielded from external hum fields. Since the transformer is a coil of wire, wound specifically for good response over the complete audio ▶

spectrum, they are particularly susceptible to magnetic fields produced by power transformers etc. The problems associated with isolating the transformers from power supply hum fields can be very real, if not impossible in some instances.

It is often said that a transformer's ability to reject a common mode signal is inferior to that of a balanced preamplifier such as the one to be described in this project. Although this is true it is largely irrelevant since the limit to common mode rejection is usually set by the shielded cable used to connect the input devices. Even the best quality cables seldom allow common mode rejections greatly in excess of 60 dB, a figure which is easily surpassed by most input transformers. The main advantage of differential preamps over transformers is cost and relative lack of susceptibility to hum fields. This makes it substantially easier to mount the preamp within the equipment to avoid degradation of the signal-to-noise ratio by hum pickup. Another advantage of the preamp over transformers is that even the best transformers generate significant amounts of harmonic distortion in comparision to distortion figures easily obtained with an op-amp based balanced design.

The differential input needed is easy to implement with the help of operational amplifiers, since these have inverting and non-inverting inputs already. The simplest circuit that could be used and one that is adequate with microphones is shown in Figure 3. This circuit is the standard differential op-amp circuit and offers good performance with most balanced sources. The resistor from the non-inverting input to ground is made the same value as the feedback resistor. In this way the gain of the stage is identical for the two inputs. With the non-inverting input grounded, the gain of the stage is determined by the ratio of the resistors R2/R1. With the inverting input grounded, the gain of the op-amp is given by the standard formula

$$(R2 + R1)/R1.$$

In this case however, the input resistor in series with the non-inverting input and the resistor from this input to ground form a potential divider and attenuate the signal by an amount given by:

$$V_i = V\,(R2/(R1 + R2))$$

So the total gain of the stage at the non-inverting input is

$$((R2 + R1)/R1)\,(R2/(R1 + R2))$$

or R2/R1, which is the same as the inverting input.

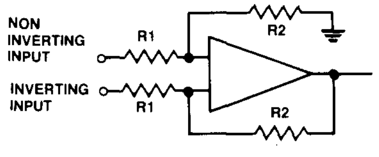


Figure 3. **Preamp stage with a simply-balanced input.**

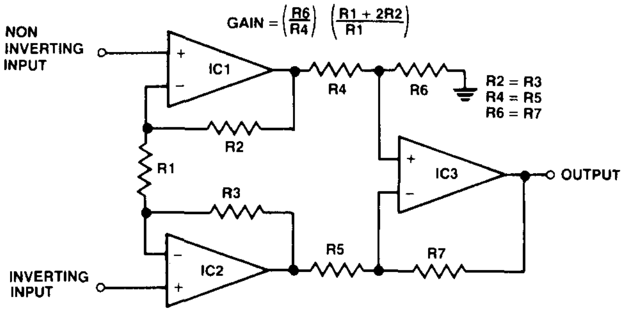


Figure 4. **The solution to the problem.**

This circuit however, has the disadvantage that the impedance to earth from each of the two inputs is very different. The impedance at the non-inverting input can usually be regarded as approximated by the series combination of the two resistors, i.e: R1 + R2. The impedance at the inverting input is simply that of the input resistor, since the inverting input is a virtual earth once feedback is applied in this way. This does not bother most balanced sources, since a true balanced source works independently of the ground connection.

The impedance seen by the balanced source is a result of that due to both input resistors and the internal impedance from base to base of the input differential pair within the op-amp. In most circuits the resistance of the input resistors completely dominates and it is sufficiently accurate to quote the input impedance to balanced sources as 2R1.

A major disadvantage of this circuit is that the ability to reject common mode signals can be seriously degraded with some sources by differences in the source impedance to the two inputs. Remember that it is the matching of the two sets of resistors that determines the common mode rejection ratio. This is the ratio of the input signal to the output signal when a common mode signal is applied. It is usually quoted in dB. The value quoted earlier for shielded cables of around 60 dB is a relatively easy figure to obtain with the op-amp circuit so long as the driving source impedance is the same for both inputs. A mismatch of only one per cent will degrade the common mode rejection ratio (CMRR) of an otherwise well designed preamp by around 20 dB, and result in a figure that could easily be unsatisfactory.

Another disadvantage of this circuit is that it is not capable of delivering the full gain needed of the preamplifier and still give satisfactory distortion figures. If we take a nominal output signal level from a balanced microphone to be around 0.2 mV and the required output from the preamp to be around 100 mV, then a gain of 500 is required, or around 54 dB. The distortion figure obtained using the best op-amps available would be unsatisfactory. For example, an NE5534N at a gain of 500 would have a distortion figure around 0.15%, a poor figure by modern standards and well outside the capabilities of a good transformer. The solution is simply to decrease the gain of the stage and add a second stage to make up the difference. This however, does not solve the problem of degradation of the CMRR on some sources. The real solution is to add a *third* op-amp to the design and implement a full instrumentation amplifier.

The basic circuit for an instrumentation amplifier is shown in Figure 4. The second stage, formed by IC3, is the same as the simple differential amplifier in Figure 3, but its inputs are buffered by the input stages formed by ICs 1 and 2. Resistor pairs R2, R3 and R4, R5 and R6, R7 are made equal. The gain of the second stage is simply R6/R4 as derived above, but the gain of the first stage is given by the slightly more complex formula:

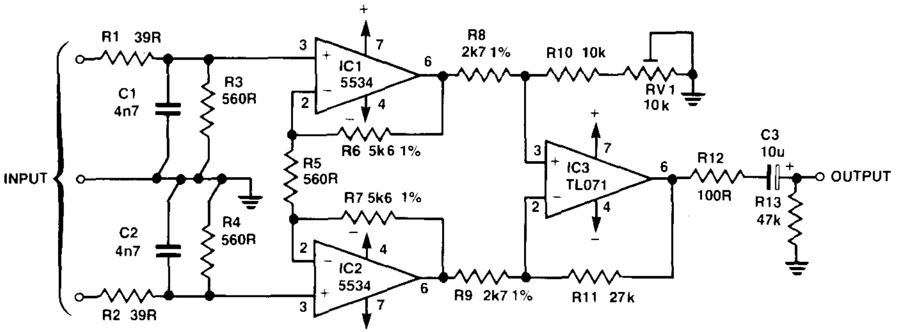
$$(R1 + 2R2)/R1$$

The overall gain is therefore

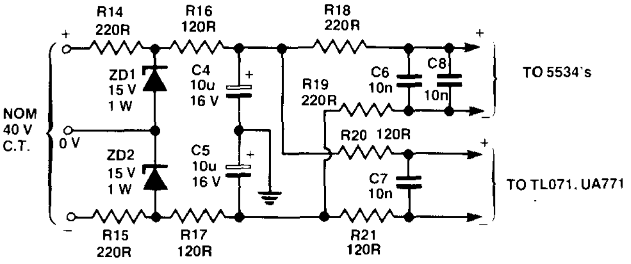
$$\frac{R6}{R4} \times \frac{R1 + 2R2}{R1}$$

If the value of R4 and R5 is made large in comparison to the estimated difference in the output impedances of the two input op-amps and if the gain of these two op-amps is the same then good CMRR will result.

A problem can occur on many instrumentation amplifiers in ensuring that



NOTE: EXTERNAL CONNECTION MUST BE PROVIDED BETWEEN POWER SUPPLY 0 V POINT AND THE SIGNAL GROUND. SEE TEXT.



the gains of the input op-amps are as close as possible to being the same. One feature of this circuit is that the CMRR is affected to a lesser extent by the matching of the resistors around the first stage. Furthermore, this will not be degraded by mismatch of the source impedance to the two inputs. The overall gain of the preamplifier is divided into two stages ensuring sufficient amounts of negative feedback to provide low distortion.

Close tolerance resistors (1% or 2%) are specified for R6, 7, 8 and 9 so that any dc inbalance between the input stages, IC1 and IC2, can be balanced out by RV1.

It is a good idea to use low noise metal oxide resistors for the input resistors, R3 and R4, to get good noise performance. They cost little more than standard carbon deposition types. Indeed, metal oxide resistors could well be used throughout, without a significant cost penalty. Most metal oxide resistors are available in 1% or 2% tolerance classes in any case.

Construction

Construction of the unit is straight forward if the ETI pc board is used, since all components are mounted on the board. The usual precautions should be taken. The circuit employs several electrolytic capacitors so be certain these and the transistors, diodes and ICs are inserted with the correct orientation. The circuit is shown to run from a nominal ±20 V supply. This ensures a clean ±15 V supply to the op-amps giving the circuit good headroom. If this voltage is not available however, the circuit will run perfectly well on a lower supply voltage. If the supply is clean regulated dc, the on-board zeners can be eliminated. If not, replace them with a lower voltage type to suit the supply voltage available. The NE5534ANs are rated for supply voltages in excess of 20 V but some second-source alternatives to the Signetics devices seem to be incapable of running on this supply voltage. If the devices you obtain do not have the NE prefix it might be wise to ensure that the supply voltage to the op-amps does not exceed 15 V. If in doubt, leave the zener diodes in circuit as shown on the pc board layout and the circuit diagram.

The pc board has been designed so that an external connection must be provided between the 0 V point on the pc board and the signal earth. The correct place for this connection is at the input to the preamplifier, i.e: on the input ▶

HOW IT WORKS — ETI-461

The circuit is a relatively straightforward instrumentation amplifier. The main differential stage is formed by IC3, the TL071. This is a BiFET op-amp with good common mode rejection ratio (CMRR) figures. This stage is buffered from the inputs by a pair of NE5534AN op-amps that also provide additional gain and determine the overall noise performance of the preamp. As mentioned in the main article, the overall gain of the preamp is determined by the gain of the first and second stages. The gain of the second stage is determined by the ratio of R11 to R9, and is around 10. The gain of the first stage is approximately 20, giving an overall gain of about 200, or 46 dB. If you require a different gain to this, try to keep the ratios of gain in the first and second stages the same. The amount of gain provided here should be suitable for most microphones, providing around 100 mV output from a 0.5 mV input signal level.

The circuit is dc coupled at the input. This assumes that the driving source will be transformer or capacitively coupled at the output, which should be a safe assumption. The input impedance of the stage is set by the two input resistors R3 and R4. To increase the input impedance, simply increase the value of these resistors.

The RC networks consisting of R1-C1 and R2-C2 are high frequency filters to reduce the circuit's susceptibility to RF interference.

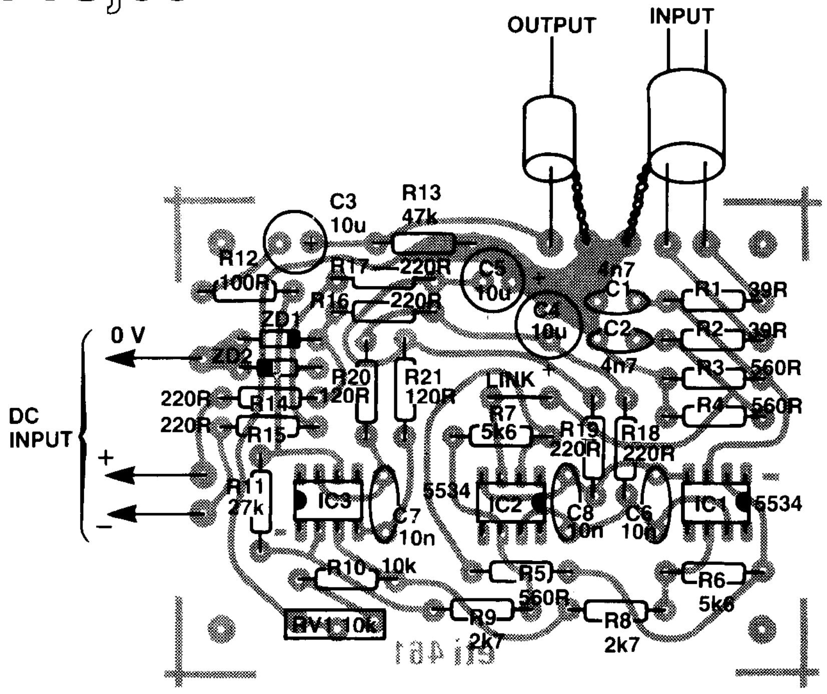
The split power supply is provided either from two zener regulators or from a well-regulated and filtered dc source. The supply pins to each IC are decoupled by 1k resistors and 10n capacitors to prevent IC-to-IC interaction and possible feedback via the supply rails.

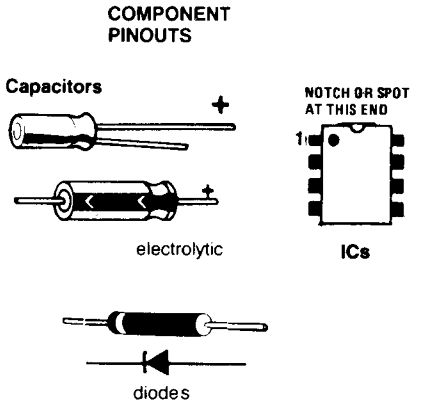
SPECIFICATIONS — ETI-461 DIFFERENTIAL PREAMPLIFIER

Frequency response (10k load)	12Hz - 60 kHz, ±0.1 dB
T.H.D. (at 5 V RMS output)	
100 Hz	‹0.007%
1 kHz	‹0.006%
10 kHz	‹0.012%

Distortion figures can be expected to decrease further at more realistic signal levels but becomes difficult to measure.

Total equivalent input noise (20 kHz bandwidth)	−124 dB (approx)
Input impedance	nominally 560 ohms to ground from each input.
Output impedance	nominally 260 ohms
Common mode rejection ratio	depends on calibration but easily adjusted to 80 dB.





socket. A separate wire is run from the 0 V point to the signal earth point of the input socket. The signal leads from the input socket to the pc board should be shielded cable with the earth braid connected at both ends. The signal earth should not be connected to the chassis directly. RF shielding can be accomplished by connecting a 100n capacitor between the signal earth at the input socket and the chassis. This will eliminate any problems with hum loops that might otherwise be formed around the mains earth line. If in doubt about this, consult the article on the Series 5000 power amplifier published in March 1981. This article describes in detail the earthing arrangement and the principles employed in power amp design are similar to those needed for good earthing of a preamplifier.

Performance

This preamplifier is capable of excellent performance. The noise figures obtained are, to a large extent, determined by the choice of op-amp used. With the NE5534AN the noise figures and distortion performance quoted in the specifications table can be expected. An equally important parameter is of course the slew rate and slew-induced distortion (SID) characteristics of the design. The open loop frequency response of the op-amps used ensures an extended frequency response and all tests for slew-induced distortion gave good results.

The subjective testing of the preamp showed no sign of harshness due to slew limiting or other distortion mechanisms until very high input signal levels caused clipping of the output. The unit was tested with a number of high quality balanced microphones and several unbalanced types as well. If an unbalanced low impedance mic is to be used, the unused input is simply connected to ground at the input socket.

In all tests, the unit performed well and should prove to be a good balanced mic amplifier suitable for incorporation in a large number of high quality audio projects. ●

PARTS LIST — ETI-461

Resistors

	all ½ W, 5% unless noted
R1, R2	39R
R3, 4, 5	560R
R6, R7	5k6, 1%
R8, R9	2k7, 1%
R10	10k
R11	27k
R12	100R
R13	47k
R14, R15, 18, 19	220R
R16, R17, 20, 21	120R

Capacitors

C1, C2	4n7 greencaps
C3	10u/35 V RB electro.
C4, C5	10u/16 V RB electro.
C6, 7, 8	10n greencap

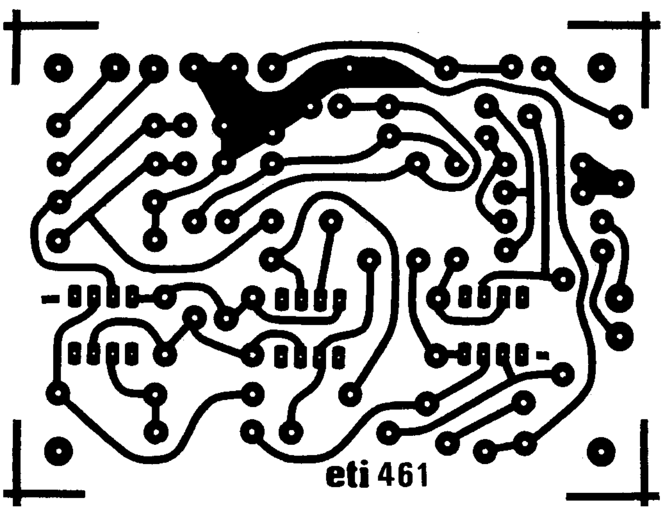
Semiconductors

IC1, IC2	NE5534N (see text)
IC3	TL071
ZD1, ZD2	15 V, 1 W zener

Miscellaneous

ETI-461 pc board

Price estimate
$18 — $20

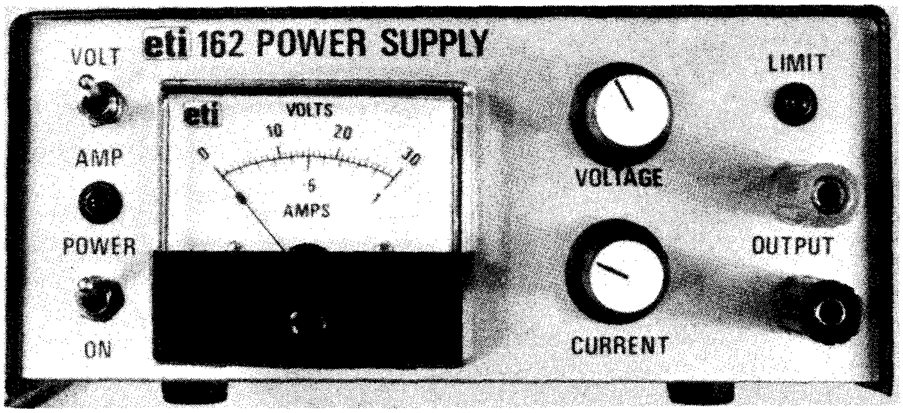


Project 162

30 V/1 A fully adjustable, protected power supply

This low cost, easy to build power supply features full protection, variable voltage output from 1.3 to 30 volts, variable current limit from zero to one amp plus metering of both voltage and current output.

David Tilbrook
Roger Harrison



Our power supply presents a neat, functional appearance. It uses low cost, readily available components and is housed in a standard 184 x 70 x 160 mm metal case. Scotchcals were made up and applied to the front panel and meter scale.

THE FIRST piece of test gear an electronics enthusiast or technician wants after a good multimeter is a *power supply*. But, exactly *what* does that hypothetical person want, we asked ourselves? After much discussion, examining past projects etc, we came up with a specification like . . . A, B, C. As he happened to be a captive in the advertising sales office, which is next door to ETI's lab, we put it to a famous Irish West Australian electronics dealer who walks on water for a hobby (see ETI, April '81, p.11), to 'test the water', so to speak. He said, "No, no, no! What they want is a power supply with D, E, F for XY.Z dollars". Conceding he might be right but that there was an element of pecuniary interest to be deducted, we counter-proposed a power supply with G, H, I but the Irishman said that would cost ZY.X dollars and no electronics person in their right mind would pay that. At this stage we thought compromise would result in a power supply with a camel-hitching rail on the front panel and thought retreat/rethink the wiser move.

Suspecting XY.Z dollars was something like $49.50 ($10 above a current kit supply and $10 below our last low-cost supply project) it was apparent some awful constraints were looming up. Rather than taking a 'better' supply and pruning it to meet a price, we started from the ground and looked at what was necessary and asked could it be done?

Obviously, a 'laboratory standard' power supply with dual digital metering, programmable voltage and current and nuclear blast proofing was not necessary. Most solid-state circuitry requires voltages between 3 V and 30 V and may require currents up to half an amp or so. Any circuitry run from the supply would need to be protected from damage by excess current should there be a fault in it, so current limiting was necessary. Current limiting also has the advantage of providing protection for the power supply if the output should be short-circuited. So, variable output up to 30 V and variable current limit were two prime goals. A pot costs less than a toggle switch so continuously variable current limiting could be included, perhaps.

Meters are a relatively expensive item. Assuming the user has a multimeter (you bought that first, remember) then the meter on the power supply only needs to read either voltage or current at any one time. Voltage metering for the supply is an obvious requirement, leaving current to the user's multimeter. But, from experience, you often need an extra meter. Thus, switched metering was desirable. Dual meters are nice, but relatively *expensive*.

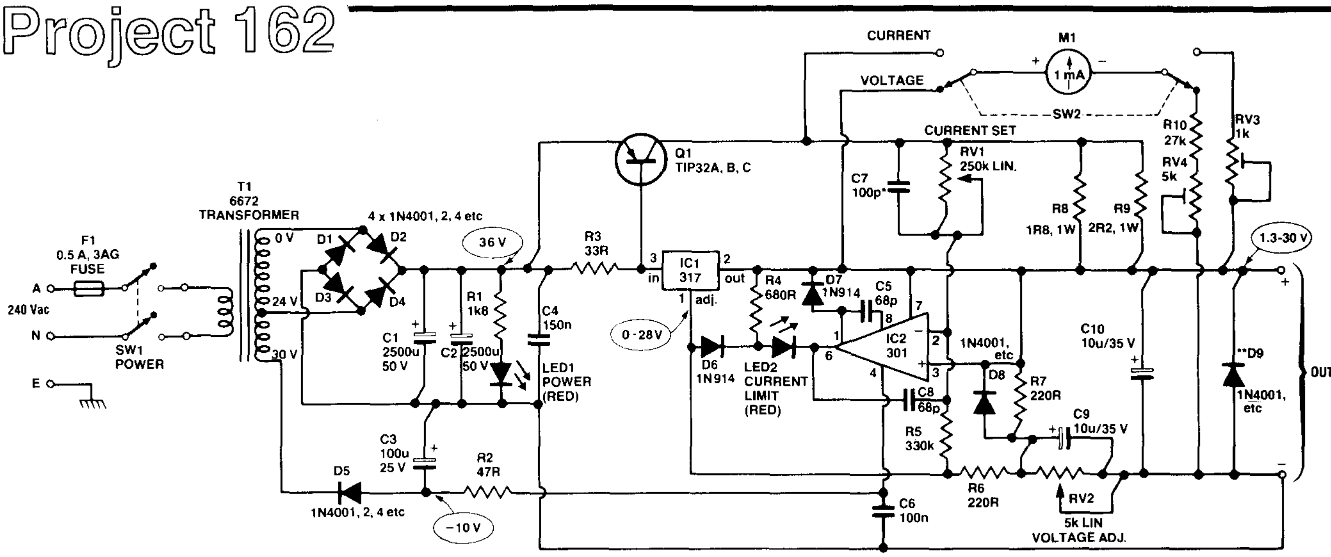
Three-terminal IC regulators are cheap, readily available and provide good results. They can also provide thermal overload protection. Internal circuitry turns them off if the case temperature of the device rises above a specified maximum. Getting a variable output from a three-terminal regulator is easy, but providing variable current limit is another matter. Use a specialised regulator? "You'd be in all sort of compost if, and it's inevitable, it was hard to get", said the Irishman-who-walks-on-water. Point there. We looked at some op-amp and transistor regulator circuits, tried one or two, but thermal overload protection was unavailable and the circuits got a little complex — and expensive. Back to the three-terminal regulator and scouring of

▶

SPECIFICATIONS — ETI-162 PROTECTED POWER SUPPLY

Output voltage	1.3— 30 V, variable
Output current	0 — 1 A, variable limiting
Output regulation	better than 0.2% zero to full load
Hum and noise on output	less than 1 mV at full load

- **LED indicates current limiting mode**
- **Output terminals isolated from chassis**



application notes. Voila! National Semiconductor's Linear Data Book had something very close to what we wanted. In next to no time (read, close to *deadline*) a circuit was lashed up and working! The project you see before you is the culmination of the aforegoing.

There were a few more parameters to consider. The case? Metal, but cheap. The transformer? Appropriately rated and available *everywhere.* The meter? Ditto. The price? On target.

Specifications are given in the accompanying table.

The design

The power supply is built around an LM317 three-terminal voltage regulator. This device, apart from being inexpensive and widely available, has the following desirable features: internal current-limiting (self-protection), thermal shutdown (more self-protection), adjustable output between 1.2 V and 37 V and excellent regulation figures. We elected to use the TO-220 flat pack style as it's easy to mount (one bolt). National and Motorola designate it LM317T. Fairchild have an equivalent designated uA317UC.

The regulator serves two purposes in this design — to provide a regulated voltage reference and thermal overload protection. The output current is supplied by a transistor. We used a TIP32, which also comes in a TO-220 package. This is a pnp device connected here as a 'collector follower'. This sort of circuit provides current amplification, but no voltage gain. The regulator and transistor are mounted side by side on a heatsink. If the output voltage and current limit are set to maximum and a short circuit occurs on the supply's output for a lengthy period, then a considerable amount of power will be dissipated in the transistor. The temperature of the heatsink will rise considerably, but before it can rise destructively, the internal thermal overload circuit of the regulator will operate and limit the maximum dissipation. You'll burn your fingers on the heatsink by the time that happens.

In normal use, at maximum dissipation the heatsink only gets warm to the touch.

Output voltage variation is provided more or less in the normal manner by 'tapping' the 'adj.' terminal across a resistive voltage divider connected across the regulator output (this involves R7 and RV2). Current limiting is provided by an op-amp. This senses the output current and 'short circuits' the voltage applied to the regulator's 'adj.' terminal. The regulator output, and thus the supply output, drops and only the predetermined current flows in the load on the supply output.

HOW IT WORKS — ETI-162

The heart of the project is the LM317 regulator, IC1. This device is used in conjunction with the main 'pass' transistor, Q1. The IC regulator compares the voltage in its output pin with that — on the 'adj.' pin and regulates the output voltage accordingly. The bias for the pass transistor is derived across resistor R3 and is due to the current drawn by the IC regulator. If the 317 detects excess voltage, for example, on its output pin, it decreases the current pulled through R3, hence decreasing the bias to Q1. In this way the 317 controls the ouput voltage and ensures good regulation for the output.

The control voltage for the 317 is derived from a potential divider formed by R7 and RV2. The electrolytic capacitor (C9) connected across RV2 is to reduce noise on the output. Diode D8 is there to discharge this capacitor in the event the output is short circuited, otherwise it will attempt to discharge via IC1 and IC2, possibly causing some damage.

Capacitor C10 is placed directly across the output to provide both circuit stability and to supply short term peak currents often required by some circuits. It also functions as a low impedance ac bypass.

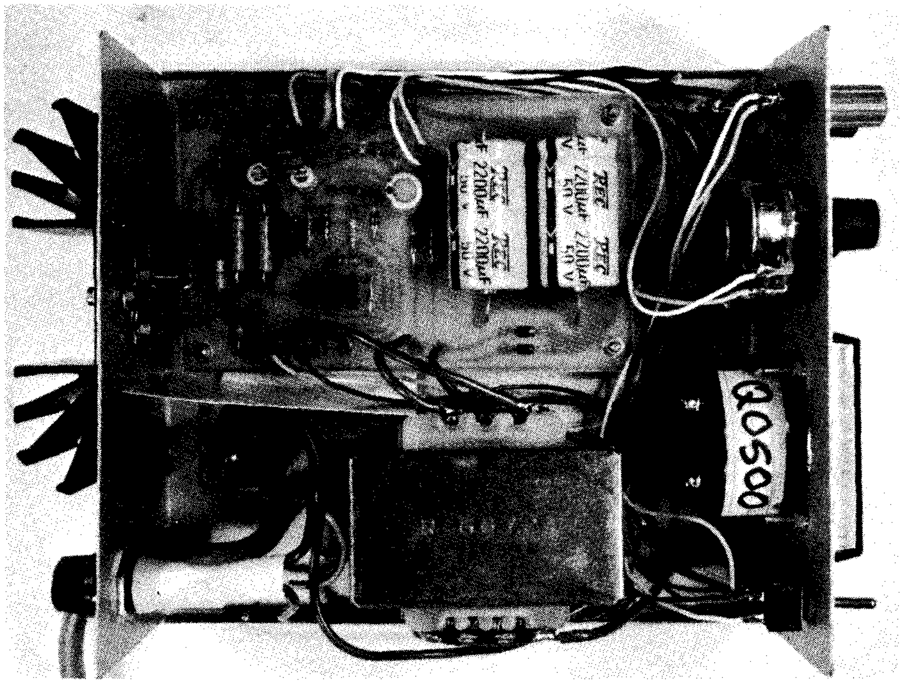
Since multiple power supplies are often used to power a single circuit, it is possible for the power supply to be supplied with a reverse voltage from an external source. To protect against this, diode D9 is included. The 1 A continuous current rating of this diode should be sufficient in most cases, and it will stand very high peak forward currents.

The remaining components are related to the variable current limit feature of this supply. The main device involved is the 301 op-amp, IC2. This device compares the output voltage, which is connected to its non-inverting input pin 3, to the voltage dropped by a potential divider formed by the CURRENT SET potentiometer (RV1) and R5. For any given setting of the CURRENT pot, the voltage on pin 2 of IC2 is proportional to the output current.

When the output current rises high enough, the voltages on pin 2 of IC2 will be 'pulled' above that on pin 3 (which is at the output voltage). The output of IC2, pin 6, then swings toward the negative rail, drawing current via D6 and LED2. LED2 will light, indicating current limit is in operation. The output of IC2 pulls down the voltage on the 'adj.' pin of IC1, lowering the output voltage.

Capacitors C5, 7 and 8 and diode D7 are included to ensure stability in the current limit stage when it is operating. This circuit uses a feature of the LM301 whereby it is capable of working as a differential amplifier with its inputs driven right up to the positive supply rail. The positive supply for the op-amp can therefore be the main output of the power supply and vary as the output voltage is varied. To ensure that the op-amp always has a supply across it, a negative supply rail has been derived by D5 and C3, a half-wave rectifier system that generates about 10 V from a tap on the secondary of T1.

The meter switch, SW2, allows the meter to be connected either as a voltmeter or a current meter. In the voltmeter position, the meter circuit is placed directly across the output with R10 and RV4 in series with M1. RV4 allows voltage calibration of the meter. When SW2 is in the current position, the meter measures the voltage drop across R8 and R9, which have the output current flowing through them. RV3 permits current calibration of the meter.



Overall internal view of the power supply. Note the cardboard 'shield' separating the mains terminal block and leads from the pc board.

Construction

For most electronic enthusiasts the mechanical work involved in a project is usually the tedious bit. We would expect most constructors to purchase a prepunched and drilled chassis, but if you want to do it yourself or plan to use a different chassis, then start by carefully laying out and marking up the metalwork. Component placement is not critical, but we would suggest you keep a strict division between the mains components and wiring and the rest of the circuitry and components. If you're using the same chassis, or something similar, then our Scotchcal front panel artwork can be used as a template for the front panel. General placement of components can be determined from the photographs. The 184 x 70 x 160 mm chassis we used could have done with some bracing of the front and rear panels. Some small brackets could be made up from scrap aluminium pieces to do this job, if you wish. If you do this, tackle it first, but make sure the brackets won't foul any components attached to the panels.

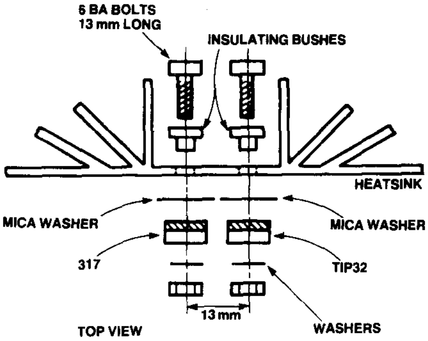
If you're using the same chassis we used and all holes are prepared, first thing to do is apply the Scotchcal front panel. We made up a metal Scotchcal, rather than plastic, as it's more durable. Carefully lift the backing from one edge and align the edge on the chassis panel. Peel off the backing and carefully smooth the Scotchcal into place across the panel making sure it's correctly aligned as you go. When it's in place, smooth out any bubbles by carefully rubbing them toward an edge. You can cut out the holes with a sharp penknife or modelling scalpel.

We also made up a metal Scotchcal label for the meter scale. Disassemble the meter and carefully apply the Scotchcal to the original scale, trim the edges if necessary and then re-assemble the meter.

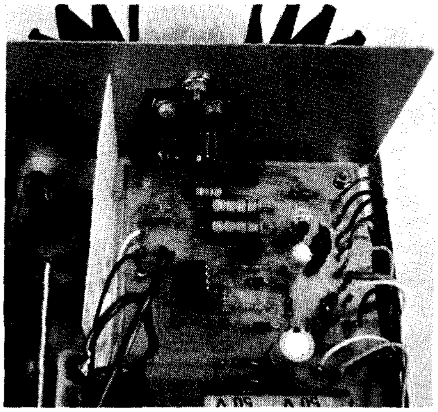
Mount the meter to the front panel first, otherwise you will have great difficulty reaching the nuts that secure it as they will be obscured by other components. Then mount the LEDs, switches, pots (and their knobs) and output terminals. On the rear panel, mount the mains fuse and install the mains cable with its clamp grommet, leaving enough of the cable protruding inside the case so that it reaches the terminal block. Mount the terminal block on the chassis bottom next, then terminate the mains cable. Make sure the green and yellow earth lead is the longest so that it's the last to break in the event of a catastrophic accident.

Insert the four pc board mounting bolts next. We used 13 mm long 6 BA bolts. Put two nuts on them to space the pc board up from the chassis. Cut a 'shield' for the mains wiring from a 70 x 70 mm piece of heavy cardboard, bend up one edge about 8 mm in and secure it under the rear mounting nut nearest the mains terminal block by punching a hole in the appropriate place in the bent-up piece — see the internal photograph.

Assemble the 317 regulator and TIP32 transistor to the heatsink next. Insulate each with a mica or plastic thermal washer and bolt insulators. Using a multimeter, check that the metal tag of each device is not shorted to the heatsink. Bend the leads of each device up from the heatsink.



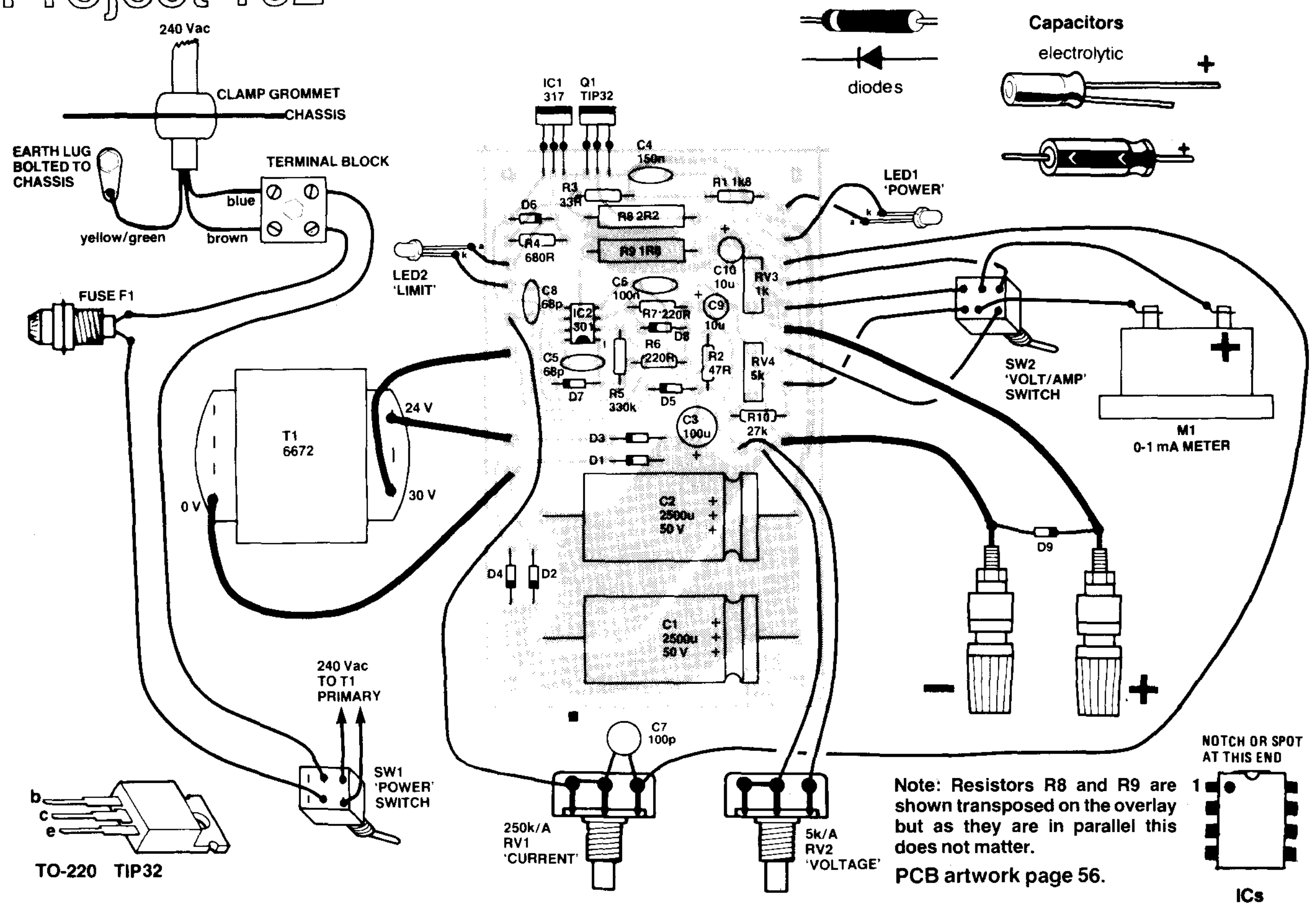
Mounting the 317 regulator and TIP32 transistor to the heatsink.



Internal view of the power supply showing mounting and terminating details for the regulator and transistor. These are assembled to the heatsink as shown above and the heatsink mounted to the rear panel using bolts above and below the cutout visible here.

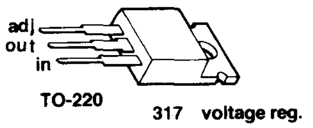
Now you can attach flying leads to all the components mounted on the front panel and between the mains terminal block and fuse to the mains switch. Put heatshrink tubing over the mains fuse and mains switch, ensuring they are well covered. Make sure all leads are long enough to reach their destination. Solder C7 to the terminals of RV1 and D9 to the output terminals, as shown in the overlay and wiring diagram.

Mount the power transformer next, oriented such that its 240 Vac input terminals are away from the pc board. Terminate the leads from the mains switch to the transformer primary connections, using heatshrink tubing again to shroud the terminals. ▶



Note: Resistors R8 and R9 are shown transposed on the overlay but as they are in parallel this does not matter.

PCB artwork page 56.



PARTS LIST — ETI-162

Resistors	all ½W, 5% unless noted
R1	1k8
R2	47R
R3	33R
R4	680R
R5	330k
R6, R7	220R
R8	1R8, 1W
R9	2R2, 1W
R10	27k
RV1	250k lin. pot.
RV2	5k lin. pot.
RV3	1k min. vertical mount trimpot
RV4	5k min. vertical mount trimpot
Capacitors	
C1, C2	2500u/50 V axial electro
C3	100u/25 V RB electro
C4	150n greencap
C5, C8	68p ceramic
C6	100n greencap
C7	100p ceramic
C9, C10	10u/35 V RB electro
Semiconductors	
D1-5, 8, 9	1N4001, 1N4002, 1N4004, EM401 etc
D6-D7	1N914, 1N4148
IC1	LM317T, uA317UC
IC2	LM301, uA301
Q1	TIP32A, B or C
LED1, 2	TIL220R red LED

Miscellaneous	
F1	0.5 A, 3AG fuse
M1	1 mA MU-45 meter, or similar
SW1, SW2	DPDT miniature toggle switches, 250 Vac/1 A rated.
T1	6672 transformer, 240 V primary, 30 V/1 A multi-tapped secondary.

ETI-162 pc board; two binding posts — one red, one black; case — metal, U-chassis & lid type; 184 x 70 x 160 mm (e.g: D.S.E. H2744, Altronics H0444, Electronic Agencies HE1742); two small knobs; mains cable, clamp grommet and terminal strip; fuseholder; Scotchcal panel and meter scale; heatshrink tubing; heatsink — flat sided radial fin type, 30 mm long (e.g: Rod Irving HS1); nuts, bolts, hookup wire etc.

Price estimate
$45 — $50

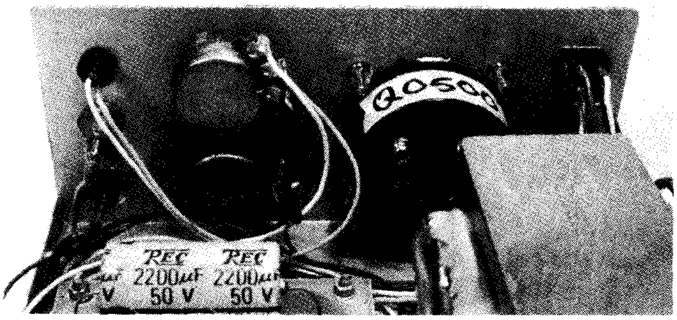
Note that this is an **estimate** only and **not** a recommended price. A variety of factors may affect the price of a project, such as — quality of components purchased, type of pc board (fibreglass or phenolic base), type of front panel supplied (if used), etc — whether bought as separate components or made up as a kit.

Now you can tackle the pc board. Start with all the resistors. Then mount the two trimpots. Next, solder all the semiconductors in place. It is *most important* you get all of these the right way round, especially the rectifier diodes. The capacitors can be mounted next. There are five electrolytics and all have to be mounted with the correct orientation. Note that the two filter capacitors are given as 2500 uF in the parts list but the photograph shows 2200 uF types. Either can be used without affecting circuit operation at all. Remember, electrolytic capacitors have a very wide tolerance (like +80%, −20%). We used pc stakes to terminate the leads from the off-board components. You could use short lengths of 22 gauge tinned copper wire with a loop bent at the top, if you wish. Six 30 mm lengths of tinned copper wire are needed to connect the 317 and TIP32.

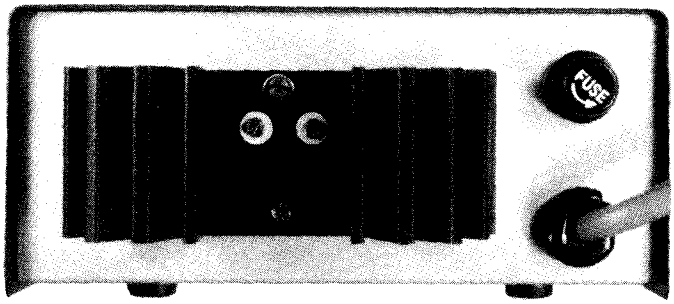
Carefully check the pc board to see that all components are mounted and the semiconductors and electrolytics are correctly polarised. Mount the pc board and terminate the flying leads from all the off-board components. Use heavy duty hookup wire from the transformer secondary to the board and from the output terminals to the board.

All OK? *Check it!*

Now you're ready to switch it on and try it out. ▶



Internal view from the rear of the front panel.



View of the rear panel showing heatsink and mains fuse placement.

Switch on

Set the CURRENT and VOLTAGE control to about half rotation and the VOLT/AMP switch to read volts on the meter. Hook your multimeter to the output, switched to the 30 V range or a higher one, plug in and switch the power supply on. If all is well, the POWER LED should light and the multimeter will read some voltage. The power supply meter will probably read something quite different. If you don't get these indications, switch off and look for a wiring error or components misplaced or incorrectly oriented.

If all is well, set the VOLTAGE control so that you get a reading of 20 V on your multimeter. Then, adjust RV4 (the trimpot nearest the front panel) until the power supply meter reads the same. Vary the VOLTAGE control and check that the supply's meter corresponds closely with the multimeter. See that you get around 1.3 V at minimum and 30 V (within 0.5 V) at maximum.

Turn the power supply off. Wind the VOLTAGE control fully anticlockwise and set the CURRENT control half way. Set the VOLT/AMP switch to read current on the supply's meter. Switch your multimeter to the 1 A range, or higher. Turn the power supply on. The LIMIT LED should light and the multimeter should indicate about half an amp of current flowing. The supply's meter will likely read something quite different. Wind up the CURRENT control so that your multimeter reads one amp. Adjust RV3 (nearest the back panel) so that the supply's meter reads the same. Vary the CURRENT control and see that the supply's meter corresponds closely to your multimeter. The LIMIT indicator should go out when the CURRENT control is at minimum.

If at any time you don't get the correct indications, or worse still — burning smells!, switch off and hunt for a fault.

If all is well, you can put the lid on your supply and put it proudly on your workbench.

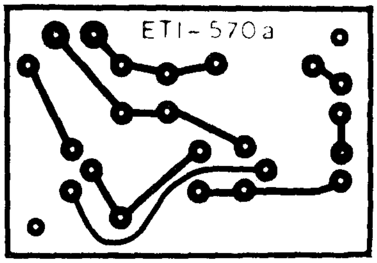
Using it

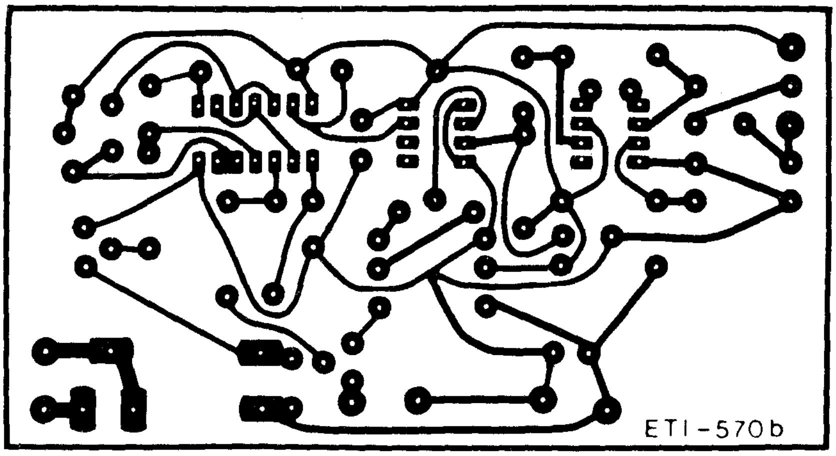
In use, you set the output voltage to what is required by the circuit you are working on then apply a short to the output terminals and set the current limit to something a little above what you judge the circuit will draw. With most CMOS circuitry, even that containing many ICs, 100 mA is a good safe limit. Allow for relay and indicator (LEDs, lamps etc) currents. A little experimentation will teach you what to expect under a wide range of circumstances.

We trust you get many useful years of use from your ETI-162 power supply. ●

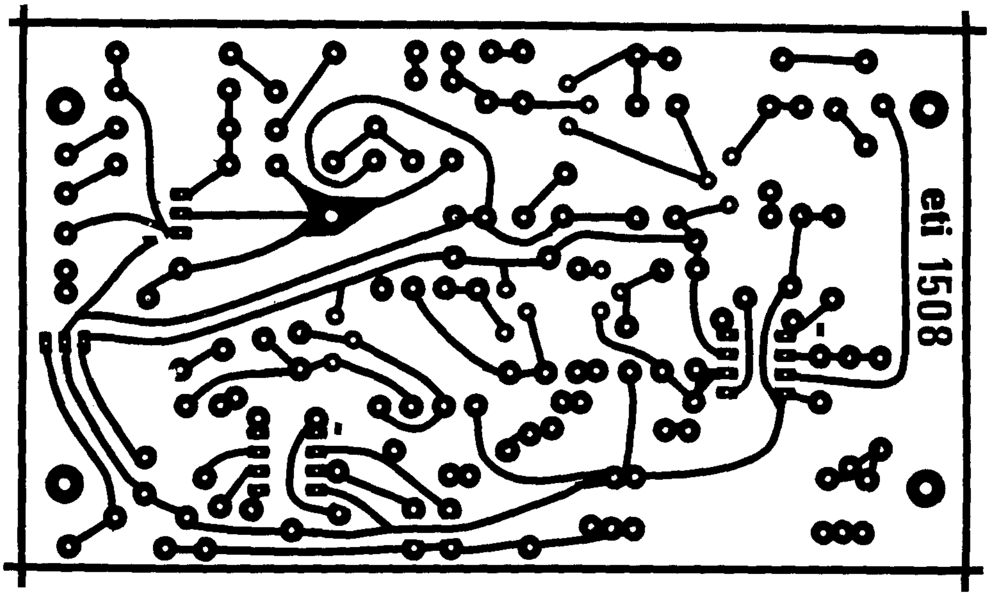
NOTE: this supply is not meant to be used as a battery charger so don't connect lead-acid batteries to it. Accidental reverse connection of a lead-acid car battery will likely destroy D9 and maybe other components. Nickel-cadmium batteries could be charged from the supply operated in the constant-current mode and D9 will prevent damage to the supply if you accidentally reverse-connect them. However, take the usual precautions regarding the charging period and charging current.

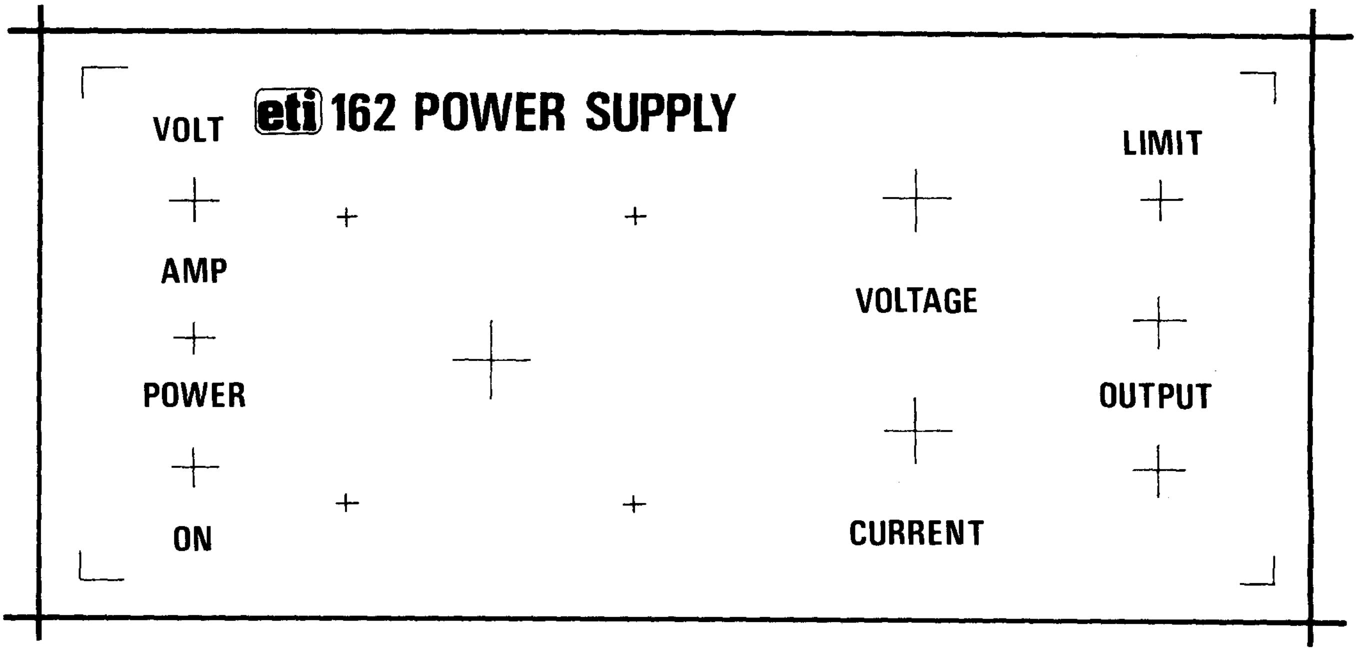
PCBs

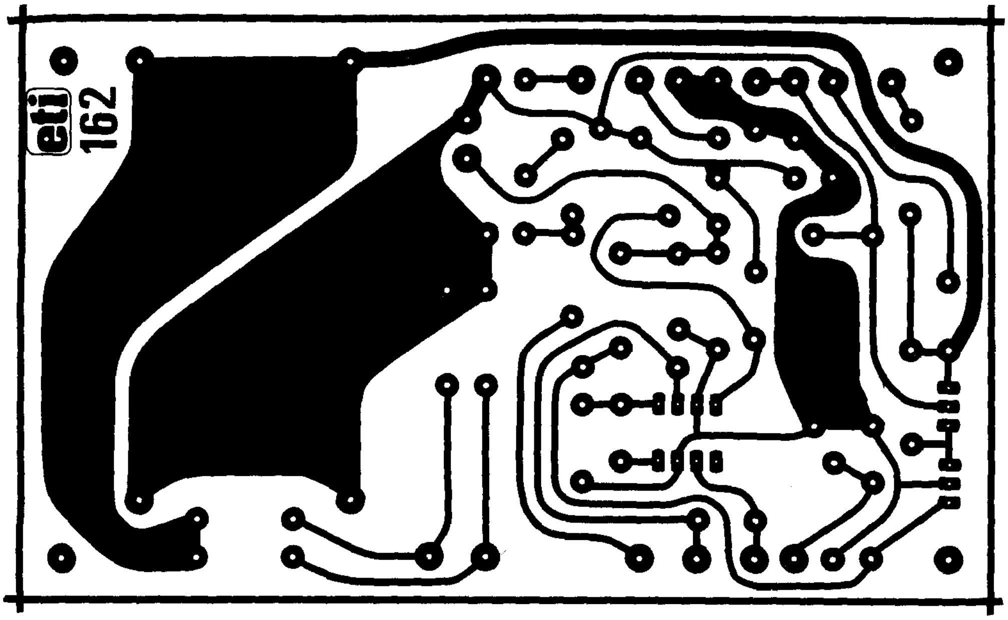


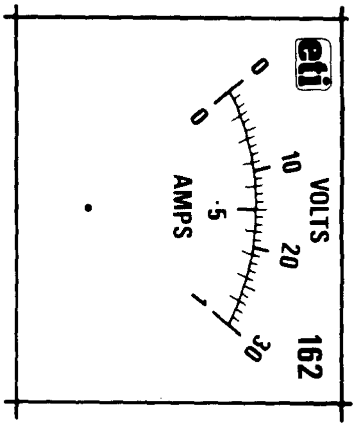


PCBs


eti 1508


eti 162 POWER SUPPLY
VOLT
AMP
POWER
ON
LIMIT
VOLTAGE
OUTPUT
CURRENT


eti 162


eti
VOLTS
·5
AMPS

Polyphonic organ features 'touch sensor' keyboard

Barry Wilkinson
Roger Harrison

Featuring a 'touch sensor' keyboard constructed right on the printed circuit board, this polyphonic organ project covers a two-octave range, has loudspeaker output plus two 'voices' and can be operated from a battery or plug pack.

BACK IN August 1976 we published the "ETI Mini Organ", Project 602. This featured a 'touch sensor' keyboard utilising tracks on the printed circuit board which, when bridged by a finger, turned on a CMOS switch. The switch turned on an RC oscillator and set the pitch of the note produced. The technique was novel and effective. An added tremolo circuit could also be switched in and out using the same technique. However, the technique had one drawback. Moisture from the fingers would sometimes build up on the keyboard and bridge the key tracks for one note or another, and the note would hold on. Wiping the keyboard with a tissue or cloth would solve that, but it proved an occasional problem nevertheless.

The ETI 602 Mini-Organ was only monophonic, that is, could only play one note at a time, a limitation that did not escape many readers and constructors. In defence, one might point out that the entire brass and woodwind family of traditional acoustic instruments are also monophonic, but an 'organ' is traditionally polyphonic, which means any number of notes in its compass can be played simultaneously. Hence, this project is a polyphonic organ.

Many notes

There are two basic ways to generate many notes that can be sounded simultaneously. You can commence with a 'master' oscillator at some suitably high frequency and have a series of frequency dividers that divide this down stage by stage to produce the required range of notes. This has the advantage that only a single tuning control is required to set all the notes on frequency. That's fine and dandy, but the pitch interval between notes in the chromatic scale (i.e: the ratio of a note to the note above or below) is based on the twelfth root of two. This means that, to produce a scale based around middle C, at least, the lowest frequency you can start off with is around 2 MHz. A string of dividers constructed from discrete ICs would consist of many devices and be quite expensive. However, there is a device called a 'top octave synthesiser' which performs this task — but further dividers are required to produce the 'usual' range of notes. The drawback is the cost — the crystal and top octave synthesiser will set you back around $30 to start with!

For cost reasons, we've chosen the second method. Twenty five oscillators have been used to generate each of the notes in a two octave-plus-one range from F below middle C to F'' above middle C.

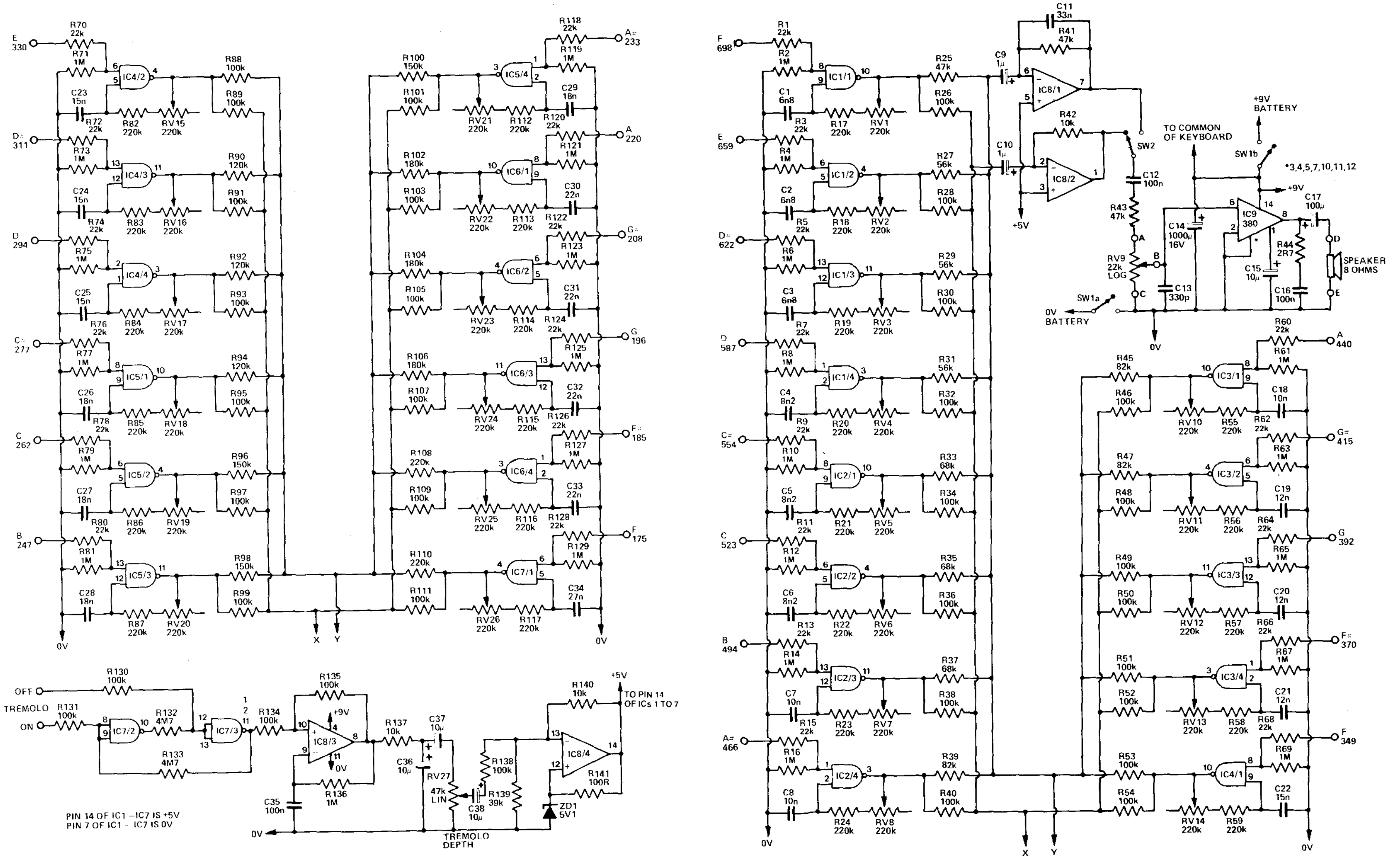
Each oscillator is implemented using a single two-input gate — and that includes the touch sensor keying! Hence all the oscillators require only seven quad-gate ICs — leaving two spare gates which have been used in the tremolo circuitry. This project uses even fewer ICs than the ETI-602 Mini Organ! In addition, Schmitt-input CMOS gates have been employed (4093s) as they have two distinct threshold points on the inputs which means they can be driven on or off with certainty, unlike conventional CMOS gates, such as the 4011s used in the ETI-602 which have only one threshold point. Using this, the problem with moisture on the keyboard holding notes on has been largely overcome. The action of each oscillator and how they are keyed is explained in detail in the *How It Works* panel.

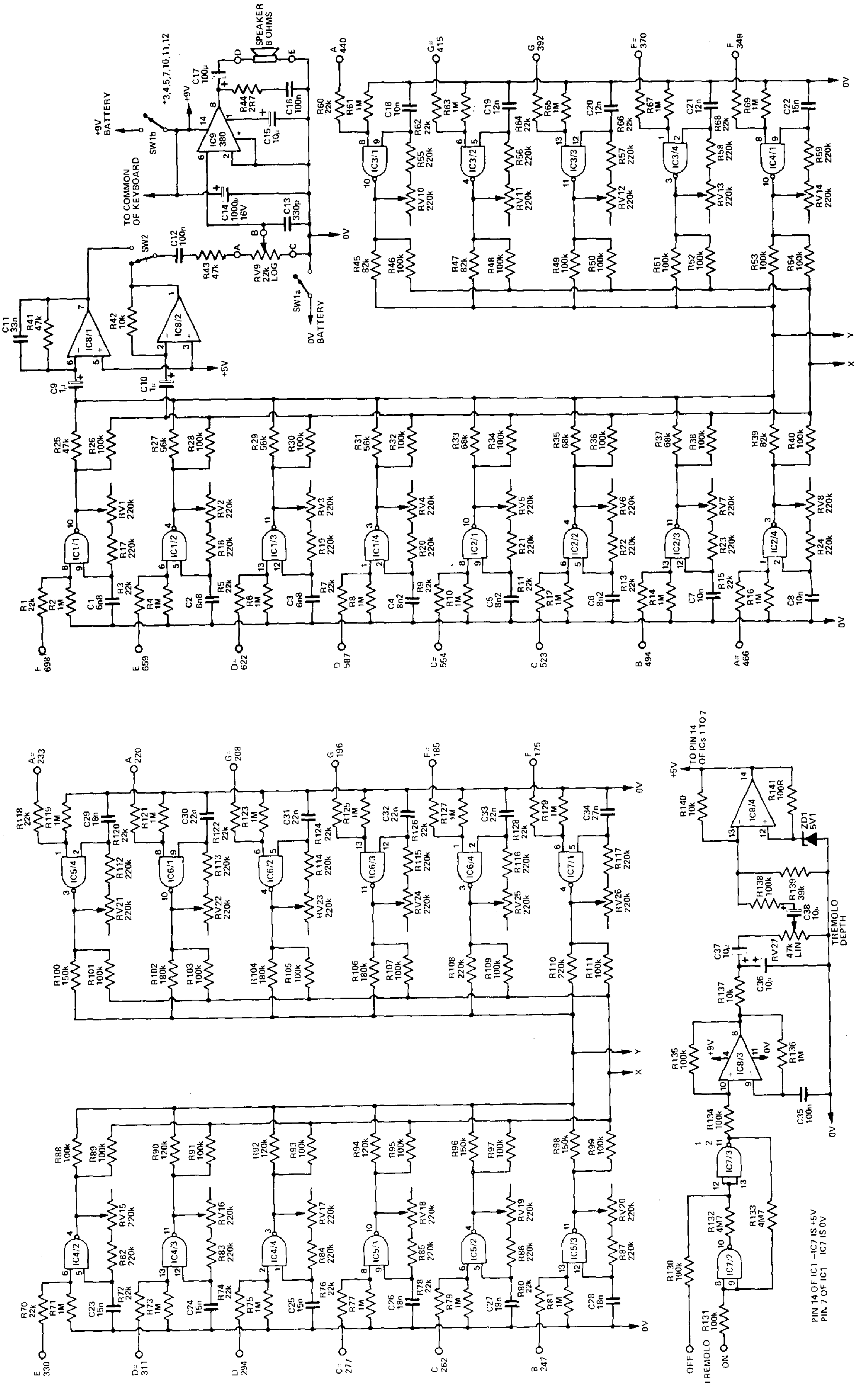
This project has tremolo circuitry and two 'voices', just like the ETI-602, but the circuitry has been arranged differently this time.

Loudspeaker output is provided by an LM380 audio power output amplifier IC. This is capable of driving 1 W into a four ohm load from a 9 V supply and for this reason we have specified the use of two small speakers. The common 50 — 75 mm diameter loudspeakers generally have an eight ohm voice coil. Connecting two in parallel gives a four ohm load and considerably more output. You can add a jack socket to take the organ's output to an external amplifier if you wish, in which case you'll get a much richer sound.

Construction

For clearly obvious reasons, you'll get best results using our pc board design. However, if you intend making your own pc board, we should point out that tarnishing of the copper on the keyboard area can be a problem. We solved that on the prototype by coating it with solder. It's a fair solution, but not all that pretty! However, we have recom- ▶


E 330
D♯ 311
D 294
C♯ 277
C 262
B 247
A♯ 233
A 220
G♯ 208
G 196
F♯ 185
F 175
F 698
E 659
D♯ 622
D 587
C♯ 554
C 523
B 494
A♯ 466
A 440
G♯ 415
G 392
F♯ 370
F 349
IC1/1
IC1/2
IC1/3
IC1/4
IC2/1
IC2/2
IC2/3
IC2/4
IC3/1
IC3/2
IC3/3
IC3/4
IC4/1
IC4/2
IC4/3
IC4/4
IC5/1
IC5/2
IC5/3
IC5/4
IC6/1
IC6/2
IC6/3
IC6/4
IC7/1
IC7/2
IC7/3
IC8/1
IC8/2
IC8/3
IC8/4
IC9 380
C9 1µ
C10 1µ
C11 33n
R41 47k
R42 10k
SW2
C12 100n
R43 47k
RV9 22k LOG
SW1a
0V BATTERY
TO COMMON OF KEYBOARD
+9V BATTERY
SW1b
*3,4,5,7,10,11,12
+9V
C14 1000µ 16V
C13 330p
C15 10µ
C16 100n
C17 100µ
R44 2R7
SPEAKER 8 OHMS
+5V
0V
X
Y
OFF
TREMOLO
ON
R130 100k
R131 100k
R132 4M7
R133 4M7
R134 100k
R135 100k
R136 1M
R137 10k
C35 100n
C36 10µ
C37 10µ
RV27 47k LIN
C38 10µ
R138 100k
R139 39k
R140 10k
R141 100R
ZD1 5V1
TREMOLO DEPTH
TO PIN 14 OF ICs 1 TO 7
PIN 14 OF IC1 – IC7 IS +5V
PIN 7 OF IC1 – IC7 IS 0V


+9V BATTERY
SW1b
*3,4,5,7,10,11,12
SPEAKER 8 OHMS
IC9 380
C17 100µ
R44 2R7
C16 100n
C15 10µ
TO COMMON OF KEYBOARD
C14 1000µ 16V
C13 330p
SW2
C12 100n
R43 47k
RV9 22k LOG
SW1a
0V BATTERY
C11 33n
R41 47k
IC8/1
IC8/2
R42 10k
C9 1µ
C10 1µ
+5V
F 698
E 659
D♯ 622
D 587
C♯ 554
C 523
B 494
A♯ 466
A 440
G♯ 415
G 392
F♯ 370
F 349
IC1/1
IC1/2
IC1/3
IC1/4
IC2/1
IC2/2
IC2/3
IC2/4
IC3/1
IC3/2
IC3/3
IC3/4
IC4/1
0V
Y
X
E 330
D♯ 311
D 294
C♯ 277
C 262
B 247
A♯ 233
A 220
G♯ 208
G 196
F♯ 185
F 175
IC4/2
IC4/3
IC4/4
IC5/1
IC5/2
IC5/3
IC5/4
IC6/1
IC6/2
IC6/3
IC6/4
IC7/1
TO PIN 14 OF ICs 1 TO 7
R140 10k
IC8/4
R141 100R
ZD1 5V1
R138 100k
R139 39k
C38 10µ
RV27 47k LIN
TREMOLO DEPTH
C37 10µ
C36 10µ
R137 10k
R135 100k
IC8/3
R136 1M
C35 100n
R134 100k
IC7/3
R132 4M7
R133 4M7
IC7/2
R130 100k
R131 100k
OFF
TREMOLO
ON
PIN 14 OF IC1 –IC7 IS +5V
PIN 7 OF IC1 - IC7 IS 0V

HOW IT WORKS — ETI-905

A total of 25 separate oscillators are used to provide polyphonic output covering two octaves. Each oscillator is individually adjustable so that they can be accurately tuned to the required note. Apart from the set of note oscillators, there are three other sections to the circuitry: the tremolo circuitry, the voice selection/mixing and the audio output stage.

THE NOTE OSCILLATORS

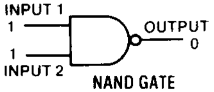
All the note oscillators have identical circuitry, only the frequency determining components are varied to provide the individual frequencies for the notes. The note oscillators are based on one gate from a 4093 CMOS two-input Schmitt trigger NAND gate. The basic circuit is shown in Figure 1.

The one gate combines both an oscillator and the keying action. What makes the gate oscillate is the feedback loop from the gate output to Input 2 via the trimpot and resistor in series and involving the capacitor C.

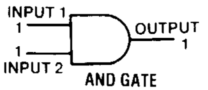
A NAND gate is a digital IC and it operates according to certain 'rules', spelled out in a 'truth table'. Voltage levels on the gate's inputs or output are either 'high' or '1', which means they're at the positive supply voltage, or they're 'low' or '0', which means they are at the 0 V rail. With a two-input AND gate, the output will be high if Input 1 AND Input 2 are high, otherwise the output is low. Hence the name, AND. The NAND gate is a NOT AND gate which simply means that its output is inverted to that of the AND gate. Thus, if Input 1 and Input 2 are both high, the output will be low, not high. The truth table for a NAND gate is given in Table 1.

TABLE 1.

Input A	Input B	Output
'0' (low)	'0' (low)	'1' (high)
'1' (high)	'0' (low)	'1' (high)
'0' (low)	'1' (high)	'1' (high)
'1' (high)	'1' (high)	'0' (low)



INPUT 1(1) NOT AND INPUT 2(1) = OUTPUT (0)



INPUT 1(1) AND INPUT 2(1) = OUTPUT (1)

While we said that a '1' or high normally means the supply voltage and '0' or low the 0 V rail, the inputs of a NAND gate are generally specified to operate for voltages between these extremes. With a normal CMOS gate there is an input level threshold of about 50%. This means that if the input is at a level above 50% of the supply voltage it is high, if it is at less than 50% of the supply voltage it is low. The actual percentage (threshold) can vary from device to device (the limits are 30% to 70%). However, there is a point above which it is definitely high and a point below which it is definitely low. This is the *normal* input characteristic of CMOS gates. They only have one threshold point.

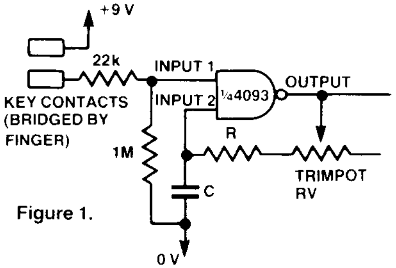


Figure 1.

With a gate having Schmitt inputs, there are two distinct thresholds: there is a low threshold which, if the input level is below that limit, the input is low and there is a high threshold which, if the input level is above that limit, the input is high. Between the two thresholds, the inputs do nothing. The low threshold may be at 40% of the supply rail, the high threshold at 60% of the supply rail.

Referring to Figure 1, in order for this circuit to oscillate, Input 1 must be driven high. Initially, it will be held low by the 1M resistor. If you look at the truth table, if either input is low, the output must remain high. Input 1 is taken high by the action of placing a finger across the key pads. Just before Input 1 goes high, the output of the gate must be high and, owing to the trimpot RV and the resistor R, Input 2 will also be high and capacitor C will be charged. Thus, when Input 1 goes high the output will immediately go low as both inputs will then be high. Input 2, however, now starts to go low due to the feedback via RV-R, but this action is slowed down by the capacitor having to discharge via RV-R. When the voltage on Input 2 reaches the low threshold, the output will suddenly go high. Thus, C will begin to charge again via RV-R. When Input 2 reaches the high threshold, the output will revert to the low condition once more and the whole cycle will be repeated.

This continues with the output going high/low/high at a rate largely determined by the RC network formed by RV, R and C. (The difference between the low and high thresholds, the hysteresis, affects it too.) By varying the resistance of the trimpot RV, the frequency of the note oscillator can be varied. The circuit will oscillate so long as Input 1 is held high by placing a finger on the key pad.

Note that each oscillator has been given a frequency variation range of 2:1 because of the values assigned to RV and R in each oscillator. The major frequency determining component in the actual circuit is thus the capacitor (C). Only standard value (E12 series) components have been specified so that components are easy to obtain and inexpensive as these are the most common values available.

VOICE SELECTION, MIXING

The output waveform of the oscillator described is a square wave, as you would no doubt have already realised. The output signals from each of the 25 oscillators are mixed together via a resistor network to the inputs of IC8/1 and IC8/2, two op-amps from an LM324 quad op-amp package. Apart from performing the mixing, this stage provides the 'voicing' as well. IC8/1 has a capacitor (C11) across the feedback resistor (R41) which changes the waveshape into a triangular form. This removes most of the harsh odd-order harmonics of the square wave, producing a 'sweeter' sound. As this type of circuit is frequency dependent, the mixing resistors from the oscillator output have different values so as to keep the amplitude constant across the frequency range. The desired voice is selected by switching between the outputs of IC8/1 and IC8/2 using SW2.

AUDIO OUTPUT STAGE

Final amplification of the signal, to drive a loudspeaker, is done by an LM380 IC power output amplifier (IC9). This can drive low impedance speakers and will deliver over one watt into a four ohm load. One or two miniature 8 ohm loudspeakers can be used for audio output. We used two 8 ohm speakers in parallel to give four ohms so that the LM380 will deliver maximum output. However, the output can be coupled to an external loudspeaker mounted in a proper enclosure (i.e: a hi-fi speaker), better sound being obtained in this way. The larger speakers are generally more efficient, which is opposite to what most people first think, and the LM380 generally clips when several notes are played together while driving the very inefficient miniature loudspeaker(s).

Capacitor C12 and resistor R43 provide some low frequency roll-off, reducing 'thump' when you touch a keypad. Volume control is provided by RV9. C13 rolls off the high frequencies, reducing the harshness of the sound. The RC network across the speaker outputs from IC9 (R44-C16) helps stabilise the LM380 at high frequencies. C17 provides dc isolation for the speaker.

TREMOLO CIRCUITRY

This part of the circuitry involves two gates from IC7 and the remaining two op-amps from IC8. Tremolo is started and stopped by touching the appropriate key pads. IC7/2 and IC7/3 are arranged as a RESET/SET (R/S) flip-flop. If pins 12-13 of IC7/3 are high, pin 11 will be low and thus pin 8-9 will be low, pulled down via R133. This is the 'tremelo off' condition. If pins 8-9 of IC7/2 are pulled high by touching the ON key pad, pin 10 of IC7/2, which would have initially been high, will go low, as will pins 12-13 of IC7/3. Thus, pin 11 of IC7/3 will go high. This is the 'tremolo on' condition.

Now, IC8/3 is arranged as a low frequency oscillator. When pin 10 of IC8/3, the non-inverting input, is low, pin 8 is held low, and so will pin 9 because of the feedback via R136. C35 will be discharged. When pin 10 of IC8/3 is driven high, pin 8 will go high too and C35 will begin to charge via R136. The voltage on pin 9 of IC8/3, the inverting input, will begin to rise at a rate determined by the RC combination of C35-R136. As the voltage on pin 9 rises, the voltage on the output of IC8/3, pin 8, will begin to fall — and so will the voltage on pin 10, the non-inverting input, because of feedback via R135. At a certain level, the op-amp output will be rapidly driven low by the feedback action, C35 will discharge and the whole cycle will start again. Thus, IC8/3 oscillates. It will do so at a rate of about 10 Hz, determined by the component values chosen.

The output is filtered to more or less a triangular shape by the RC network of R137-C36. Capacitor C37 provides dc blocking, the output being applied to the tremolo depth control, RV27. The signal is applied to the inverting input of IC8/4 which is a dc amplifier stage. The output of this stage is set to an average of about 5 V as the non-inverting input is 'clamped' at about 5 V by the zener ZD1. When the modulating signal from the 10 Hz oscillator is applied to the inverting input of IC8/4, the output voltage will swing about a 5 V mean, modulating the supply voltage to all the oscillators. The amplitude of the swing is determined by the tremolo depth control. Varying the supply voltage to the oscillators causes a small frequency variation, producing the tremolo effect. ▶

HOW IT WORKS — ETI-905

A total of 25 separate oscillators are used to provide polyphonic output covering two octaves. Each oscillator is individually adjustable so that they can be accurately tuned to the required note. Apart from the set of note oscillators, there are three other sections to the circuitry: the tremolo circuitry, the voice selection/mixing and the audio output stage.

THE NOTE OSCILLATORS

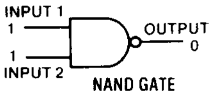
All the note oscillators have identical circuitry, only the frequency determining components are varied to provide the individual frequencies for the notes. The note oscillators are based on one gate from a 4093 CMOS two-input Schmitt trigger NAND gate. The basic circuit is shown in Figure 1.

The one gate combines both an oscillator and the keying action. What makes the gate oscillate is the feedback loop from the gate output to Input 2 via the trimpot and resistor in series and involving the capacitor C.

A NAND gate is a digital IC and it operates according to certain 'rules', spelled out in a 'truth table'. Voltage levels on the gate's inputs or output are either 'high' or '1', which means they're at the positive supply voltage, or they're 'low' or '0', which means they are at the 0 V rail. With a two-input AND gate, the output will be high if Input 1 AND Input 2 are high, otherwise the output is low. Hence the name, AND. The NAND gate is a NOT AND gate which simply means that its output is inverted to that of the AND gate. Thus, if Input 1 and Input 2 are both high, the output will be low, not high. The truth table for a NAND gate is given in Table 1.

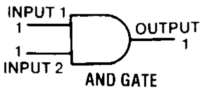
TABLE 1.

Input A	Input B	Output
'0' (low)	'0' (low)	'1' (high)
'1' (high)	'0' (low)	'1' (high)
'0' (low)	'1' (high)	'1' (high)
'1' (high)	'1' (high)	'0' (low)



NAND GATE

INPUT 1(1) NOT AND INPUT 2(1) = OUTPUT (0)



AND GATE

INPUT 1(1) AND INPUT 2(1) = OUTPUT (1)

While we said that a '1' or high normally means the supply voltage and '0' or low the 0 V rail, the inputs of a NAND gate are generally specified to operate for voltages between these extremes. With a normal CMOS gate there is an input level threshold of about 50%. This means that if the input is at a level above 50% of the supply voltage it is high, if it is at less than 50% of the supply voltage it is low. The actual percentage (threshold) can vary from device to device (the limits are 30% to 70%). However, there is a point above which it is definitely high and a point below which it is definitely low. This is the *normal* input characteristic of CMOS gates. They only have one threshold point.

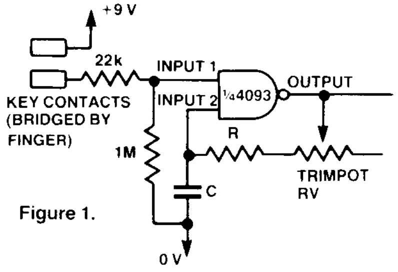


Figure 1.

With a gate having Schmitt inputs, there are two distinct thresholds: there is a low threshold which, if the input level is below that limit, the input is low and there is a high threshold which, if the input level is above that limit, the input is high. Between the two thresholds, the inputs do nothing. The low threshold may be at 40% of the supply rail, the high threshold at 60% of the supply rail.

Referring to Figure 1, in order for this circuit to oscillate, Input 1 must be driven high. Initially, it will be held low by the 1M resistor. If you look at the truth table, if either input is low, the output must remain high. Input 1 is taken high by the action of placing a finger across the key pads. Just before Input 1 goes high, the output of the gate must be high and, owing to the trimpot RV and the resistor R, Input 2 will also be high and capacitor C will be charged. Thus, when Input 1 goes high the output will immediately go low as both inputs will then be high. Input 2, however, now starts to go low due to the feedback via RV-R, but this action is slowed down by the capacitor having to discharge via RV-R. When the voltage on Input 2 reaches the low threshold, the output will suddenly go high. Thus, C will begin to charge again via RV-R. When Input 2 reaches the high threshold, the output will revert to the low condition once more and the whole cycle will be repeated.

This continues with the output going high/low/high at a rate largely determined by the RC network formed by RV, R and C. (The difference between the low and high thresholds, the hysteresis, affects it too.) By varying the resistance of the trimpot RV, the frequency of the note oscillator can be varied. The circuit will oscillate so long as Input 1 is held high by placing a finger on the key pad.

Note that each oscillator has been given a frequency variation range of 2:1 because of the values assigned to RV and R in each oscillator. The major frequency determining component in the actual circuit is thus the capacitor (C). Only standard value (E12 series) components have been specified so that components are easy to obtain and inexpensive as these are the most common values available.

VOICE SELECTION, MIXING

The output waveform of the oscillator described is a square wave, as you would no doubt have already realised. The output signals from each of the 25 oscillators are mixed together via a resistor network to the inputs of IC8/1 and IC8/2, two op-amps from an LM324 quad op-amp package. Apart from performing the mixing, this stage provides the 'voicing' as well. IC8/1 has a capacitor (C11) across the feedback resistor (R41) which changes the waveshape into a triangular form. This removes most of the harsh odd-order harmonics of the square wave, producing a 'sweeter' sound. As this type of circuit is frequency dependent, the mixing resistors from the oscillator output have different values so as to keep the amplitude constant across the frequency range. The desired voice is selected by switching between the outputs of IC8/1 and IC8/2 using SW2.

AUDIO OUTPUT STAGE

Final amplification of the signal, to drive a loudspeaker, is done by an LM380 IC power output amplifier (IC9). This can drive low impedance speakers and will deliver over one watt into a four ohm load. One or two miniature 8 ohm loudspeakers can be used for audio output. We used two 8 ohm speakers in parallel to give four ohms so that the LM380 will deliver maximum output. However, the output can be coupled to an external loudspeaker mounted in a proper enclosure (i.e: a hi-fi speaker), better sound being obtained in this way. The larger speakers are generally more efficient, which is opposite to what most people first think, and the LM380 generally clips when several notes are played together while driving the very inefficient miniature loudspeaker(s).

Capacitor C12 and resistor R43 provide some low frequency roll-off, reducing 'thump' when you touch a keypad. Volume control is provided by RV9. C13 rolls off the high frequencies, reducing the harshness of the sound. The RC network across the speaker outputs from IC9 (R44-C16) helps stabilise the LM380 at high frequencies. C17 provides dc isolation for the speaker.

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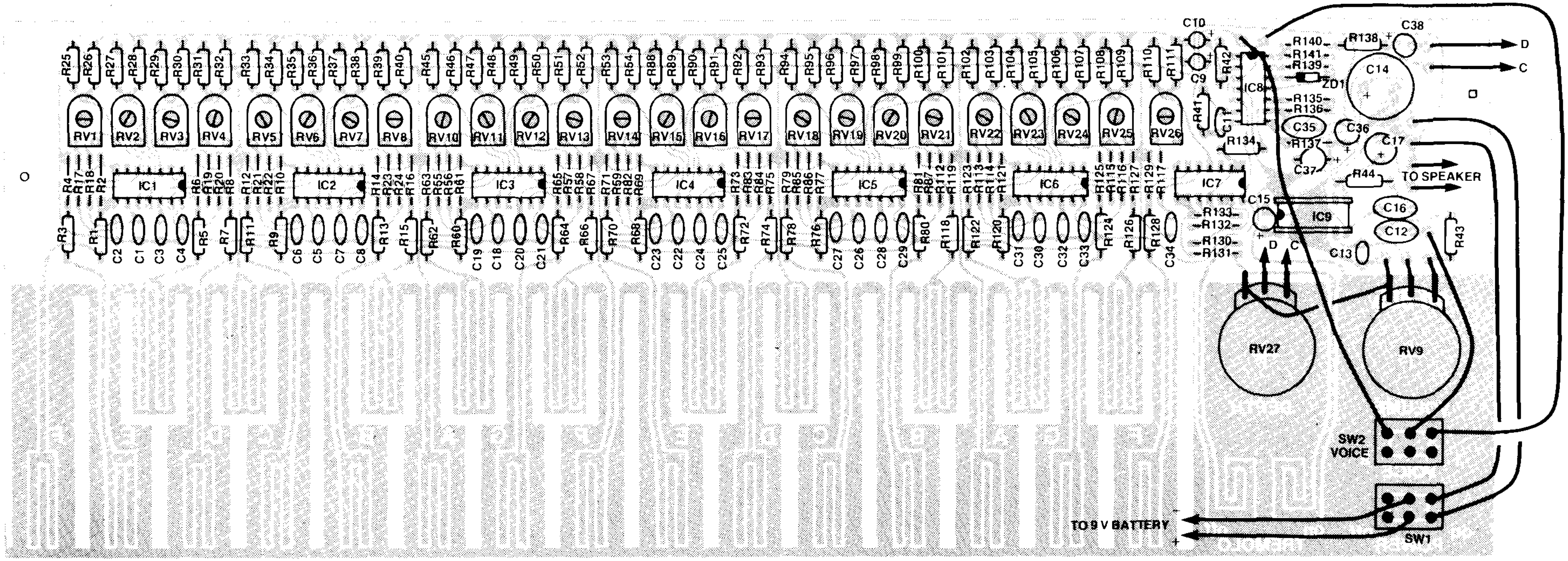


ETI-905 POLYPHONIC ORGAN PARTS LIST

Resistors		R30	100k	R62	22k	R91	100k	R119	1M
R1	22k	R31	56k	R63	1M	R92	120k	R120	22k
R2	1M	R32	100k	R64	22k	R93	100k	R121	1M
R3	22k	R33	68k	R65	1M	R94	120k	R122	22k
R4	1M	R34	100k	R66	22k	R95	100k	R123	1M
R5	22k	R35	68k	R67	1M	R96	150k	R124	22k
R6	1M	R36	100k	R68	22k	R97	100k	R125	1M
R7	22k	R37	68k	R69	1M	R98	150k	R126	22k
R8	1M	R38	100k	R70	22k	R99	100k	R127	1M
R9	22k	R39	82k	R71	1M	R100	150k	R128	22k
R10	1M	R40	100k	R72	22k	R101	100k	R129	1M
R11	22k	R41	47k	R73	1M	R102	180k	R130-131	100k
R12	1M	R42	10k	R74	22k	R103	100k	R132-133	4M7
R13	22k	R43	47k	R75	1M	R104	180k	R134-135	100k
R14	1M	R44	2R7	R76	22k	R105	100k	R136	1M
R15	22k	R45	82k	R77	1M	R106	180k	R137	10k
R16	1M	R46	100k	R78	22k	R107	100k	R138	100k
R17-24	220k	R47	82k	R79	1M	R108	220k	R139	39k
R25	47k	R48	100k	R80	22k	R109	100k	R140	10k
R26	100k	R49-54	100k	R81	1M	R110	220k	R141	100R
R27	56k	R55-59	220k	R82-87	220k	R111	100k		
R28	100k	R60	22k	R88-89	100k	R112-117	220k		
R29	56k	R61	1M	R90	120k	R118	22k		

RV1-8	220k miniature trimpot, horizontal mounting.
RV9	22k log. pot. (or 20k)
RV10-26	220k miniature trimpot, horizontal mounting.
RV27	47k lin. pot (or 50k)

Capacitors

C1-3	6n8 greencap
C4-6	8n2 greencap
C7,8,18	10n greencap
C9-10	1u/16 V tant.
C11	33n greencap
C12	100n greencap
C13	330p ceramic
C14	1000u/16 V RB electro.
C15	10u/16 V RB electro.
C16	100n greencap
C17	100u/16 V RB electro.
C19-21	12n greencap
C22-25	15n greencap
C26-29	18n greencap
C30-33	22n greencap
C34	27n greencap
C35	100n greencap
C36-38	10u/16 V RB electro.

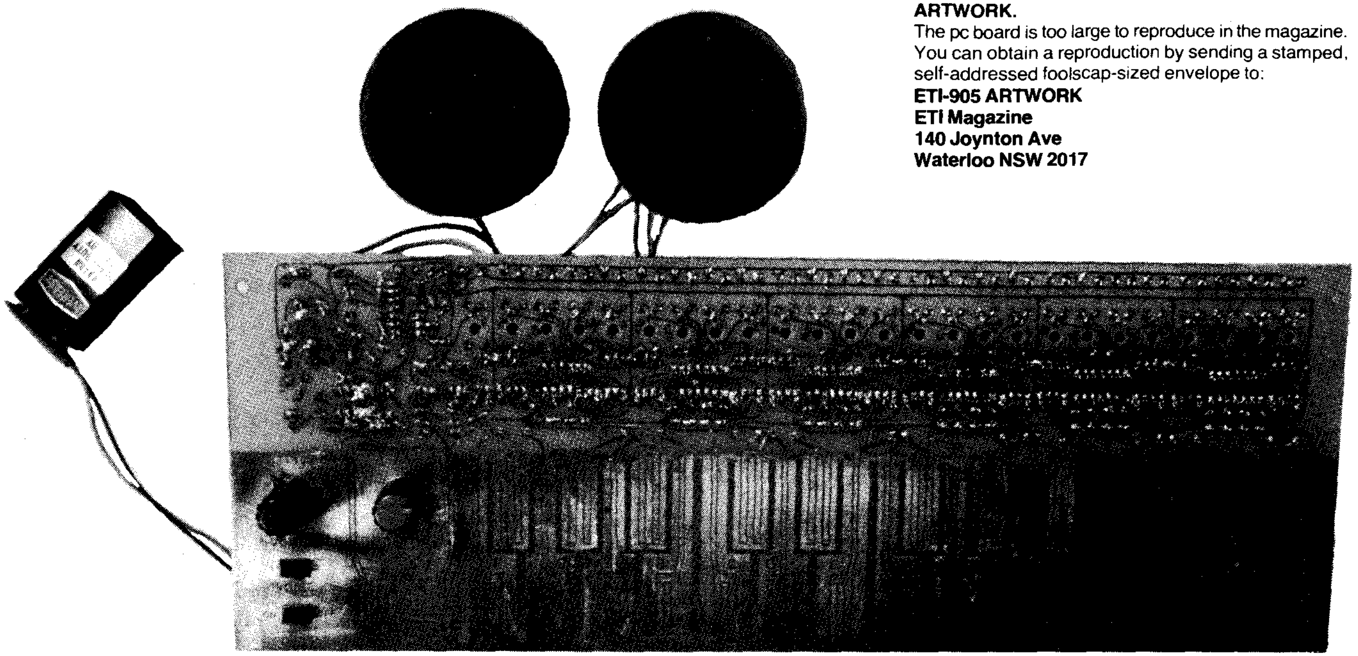
Semiconductors

IC1-IC7	4093B
IC8	LM324N, uA324PC
IC9	LM380N
ZD1	5V1 zener

Miscellaneous

ETI-905 pc board; SW1 — DPST slide switch; SW2 — SPDT slide switch; one or two 50 mm diameter 8 ohm speakers; battery holder to take 6 x AA cells; two small knobs; 30 x 30 mm square of tinplate or copper shim; hookup wire; case, etc.

Price estimate
$50 — $55



ARTWORK.
The pc board is too large to reproduce in the magazine. You can obtain a reproduction by sending a stamped, self-addressed foolscap-sized envelope to:

ETI-905 ARTWORK
ETI Magazine
140 Joynton Ave
Waterloo NSW 2017

RESISTOR SHOPPING LIST

As there are so many resistors used, here is a 'shopping list' to assist you. The Parts List can be referred to in conjunction with the component overlay when assembling the pc board.

2R7	x1	**82k**	x3
100R	x1	**100k**	x34
10k	x3	**120k**	x3
22k	x25	**150k**	x3
39k	x1	**180k**	x3
7k	x3	**220k**	x27
56k	x3	**1M**	x26
68k	x3	**4M7**	x2

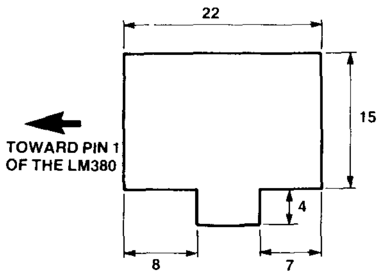
POTS & TRIMPOTS

22k	(or 20k) log pot.	x1
47k	(or 50k) lin pot.	x1
220k	min. horizontal mount trimpots	x25

mended to all the pc board manufacturers making boards for this project that the keyboard area either be nickel plated or gold flashed over nickel plating. The choice of homemade board versus a bought one is up to you.

No matter whether you buy one or make your own, make a careful check of the pc board before commencing construction. Check that all the holes are drilled to the correct size. This is particularly important with the row of trimpots. You may need to drill holes near the two ends of the board, above the keyboard area, so that mounting pillars can be screwed to the board. Exactly where and what size will depend on how you're going to mount the board, and that we'll have to leave up to you. Some suggestions are given later. Check that the two slide switches fit in the slots in the pc board. Enlarge the slots with a small flat file if necessary.

Having satisfied yourself that the board's all OK, all the trimpots can be fitted first. All the resistors can be soldered in place next, mounting them right down on the pc board.



HEATSINK FLAGS, LM380

MATERIAL: TINPLATE OR COPPER SHIM TWO OFF

ALL DIMENSIONS IN MILLIMETRES

The LM380, IC9, should be soldered in place next. Make sure you orient it correctly. Now cut two 'flag' heatsinks, as shown in the accompanying illustration. You can use tinplate or thin copper 'shim'. Both can be obtained in small sheets from hardware stores. Motor spares stores may also stock copper shim. Tin the two tags at the botton, each on the side that solders to the LM380 pins. You'll need an iron capable of supplying quite a bit of heat and having a 'chisel' bit (see ETI, October '81, A Good Joint is Hard to Find . . .). Don't overdo the solder. Then, carefully tin pins 3-4-5 and 10-11-12 on the LM380. Take one of the flags and orient it as shown in the diagram. Hold the tag with the solder side against the appropriate pins of the LM380 using a pair of pliers. Apply the flat of the iron to the tag until you see the solder flows freely. Remove the iron and *keep the flag steady until the solder sets*. This process is known as 'sweating'. If you hold the flag with your fingers while doing this you'll know exactly what it means! Now sweat the other flag to the other set of pins of the LM380. Do this carefully. While the LM380 is quite rugged, don't overdo it with the soldering iron. If you make a slip and have to resolder it, let it all cool down first.

Having accomplished that task, insert all the other ICs and solder them in place, making sure — as always — you have them correctly oriented. ICs 1 to 7 are CMOS types. Use either an isolated soldering iron or an iron with an earthed tip. Handle the ICs by their ends, avoiding touching the pins. Solder the supply pins (7 and 14) first.

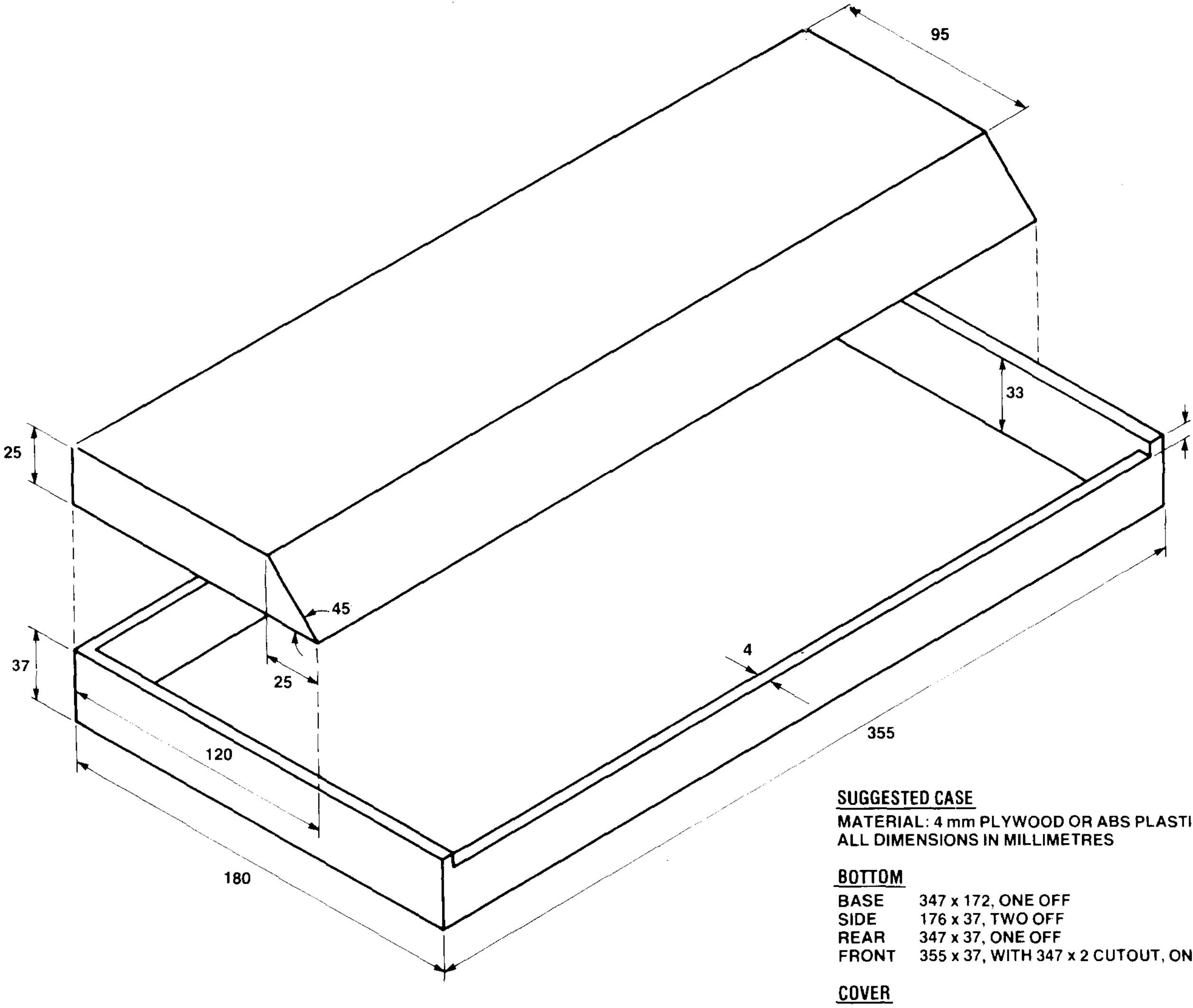
Now come the capacitors. The only thing you have to watch for here is the polarity of the electrolytics and tantalums.

It's probably a good idea at this stage to have a quick check over what you've done so far.

Now attach all the leads that run from the pc board to the two potentiometers, the two switches and the speaker(s). The three wires adjacent to C12 that run to the volume pot RV9 should be tinned copper wire. It makes life easier in a moment.

Now mount the two potentiometers, RV9 and RV27, and wire them up. Follow with SW1 and SW2. We glued our switches in place with quick-setting epoxy, but they could be screwed to the board. Attach the speaker(s) and the battery clip. Put knobs on the two potentiometer shafts.

Resist the urge to plug in a battery and try it out (it'll be out of tune anyway). First, *check everything*. Check the IC orientations especially. All OK? Now you're ready for the next bit. ▶



SUGGESTED CASE

MATERIAL: 4 mm PLYWOOD OR ABS PLASTIC SHEET
ALL DIMENSIONS IN MILLIMETRES

BOTTOM

BASE	347 x 172, ONE OFF
SIDE	176 x 37, TWO OFF
REAR	347 x 37, ONE OFF
FRONT	355 x 37, WITH 347 x 2 CUTOUT, ONE OFF

COVER

TOP	355 x 95, ONE OFF
SIDE	120 x 25, 25 x 45° CUTOUT, TWO OFF
FRONT	355 x 35, CHAMFERED EDGES, ONE OFF
REAR	347 x 21, ONE OFF

First try out

Set the VOICE switch to 2, DEPTH control fully anticlockwise (minimum) and the volume control about one-quarter advanced. Set all the trimpots to half travel. Switch on and touch one of the note keys. You should get a sound in the speaker. If not, try several other keys up and down the keyboard. Try VOICE 2 if you still get no response. If nothing happens there either, switch off and check connections and component orientations again. Correct any faults and try again. If you still have problems, check the voltage across pins 2 and 14 (+ve) of IC9 and pins 11 and 4 (+ve) of IC8. There should be 9 V or so on each. Also check that there's about 5 V across ZD1. With the TREMOLO off, check the voltage between the 0 V rail and pin 11 of IC8. There should be 5 V there. Then check the voltage between pins 1 and 14 (+ve) of ICs 1 to 7. There should be 5 V on each IC.

If all this checks out OK, you're going to have to do a bit of signal tracing. All this needs is a high impedance crystal earpiece and a 100n capacitor in series with one lead. With one lead on the 0 V rail, put the other lead on pin 2 of IC8 and touch one of the keys. You should get a sound. Try several other keys, or all of them, to see that you get a sound from each group of oscillators. If not, then check the circuitry around ICs 1 to 7. If the oscillators work, check that you're also getting signal across the two outer terminals of the volume control, RV9. If not, the fault is probably in the wiring of SW2 or IC8 is faulty. If you do get signal there, check with the earpiece that you're getting signal at pin 6 of the LM380. If not, RV9 wiring is probably faulty. If signal's there, check to see that it may be on pin 8 of the LM380. If so, then the speaker(s) or speaker wiring is faulty. If no signal there, the LM380 is probably faulty.

When the note oscillators work, try out the tremolo. If it doesn't work, check that IC7/2 and /3 is working correctly. You can do this with a multimeter. If that's OK, see that, with Tremolo ON, the multimeter needle vibrates when looking at the output (pin 11) of IC8/4.

Got it going? Now for that grand old Chinese ceremony "chu ning".

Tuning it up

First of all, put out the cat, tie up the dog and send the rest of the household away. This may be painful to others. If you possibly can, get hold of a digital frequency meter. Using one of these is by far the easiest way to tune each note oscillator to the required frequency. Simply attach the DFM input across the speaker terminals, sound each note in turn and adjust that note's trimpot to the frequency given in the accompanying Table. Looking from the keyboard side of the project, the trimpot for the lowest F is at the extreme left, lowest F# is the next trimpot, lowest G is the third trimpot from the left, and so on. Make sure the Tremolo is OFF. We used a marking pen and wrote the note on the board beside each appropriate trimpot.

The next best method is to tune the ETI-905 against a piano, organ or other fixed-pitch keyboard instrument. This is simple to do by sounding the required note on the piano, or whatever, then sounding the same note on the project and tuning it so that it sounds the same pitch (no 'beats' between them). Be patient and do it carefully, don't swing the trimpot violently one way then the other. Tuning up this way is best done with the organ set to VOICE 2 and Tremolo OFF (turn the DEPTH fully anticlockwise).

There is another way, it's a little more tedious than the other methods, but yields good results, nonetheless. Get hold of a tuning fork (you could even build up and use the ETI-606 Electronic Tuning Fork, in Nov. '79 or Top Projects Vol. 6). Common tuning forks are "A 440" and "C 262" or middle C. You'll need three arms for this or a spare person. Seat yourself at a table or bench. Put a book or piece of sponge under the ETI-905 speakers. Set the VOICE switch to 2. Tremolo should be OFF. Set the tuning fork thrumming and hold the end of its shaft on the table or bench top to get a good, loud, sustained note. Touch the same note on the keyboard and adjust its trimpot so that its pitch is the same as the tuning fork's (i.e: no beats). Put the tuning fork aside and send your friend away, this next bit can be painful.

Say the note you just tuned was middle C (that's the C at the leftmost end of the keyboard). Now sound that C and the C above simultaneously, then tune the C above (C') so that there are no beats. But make sure that C' *is* above middle C. The trimpots should generally bring each oscillator into tune within a variation of ±30° of rotation from centre travel.

Now, count five notes up from middle C — C#, D, D#, E to F. Now sound F and middle C together. Tune F so that you get a pleasant sound with no beats. These two notes are now tuned a 'fifth' apart. Now sound the lowest F (right at the leftmost end of the keyboard) and the F you just tuned together. Tune the lower F so that you get no beats — making sure it's an octave lower. Now sound the topmost F and the F above middle C together and tune the topmost F for no beats. All three Fs should now be in tune. Starting at F above middle C, count up a further five notes — F#, G, G#, A to A# (B flat). Once again, tune for a pleasant sound with no beats. Then tune the A# an octave lower. The next one you will tune is D# (E flat) right up the top end of the keyboard. Tune its partner an octave lower. Where to go from here? Simple. Start down at the lower D#.

NOTE FREQUENCIES

F	698.5
E	659.3
D#	622.3
D	587.3
C#	554.4
C	523.3
B	493.9
A#	466.2
A	440.0
G#	415.3
G	392.0
F#	370.0
F	349.2
E	329.6
D#	311.1
D	293.7
C#	277.2
C	261.6 (middle C)
B	246.9
A#	233.1
A	220.0
G#	207.7
G	196.0
F#	185.0
F	174.6

PLAYING TIPS

The 'keys' should be played with the ball of the finger, not the tip. There is no "touch" to the instruments — hitting the key hard will not alter the sound in any way. This is much like a real organ. Touch the keys smoothly and firmly.

Under extremely humid conditions, or if you have greasy fingers, some trouble may be experienced with notes holding on. Wipe your hands thoroughly and the keyboard, too.

Count five notes up from the D# just above middle C — that's the G# to the right. Once again, tune for a pleasant sound with no beats, then tune the companion note an octave lower. Commencing at *that* note, count five notes up — to C#. Tune as before, then tune the octave companion (now to the right, higher in pitch). From C# above middle C, count another five notes up (F#), tune it, then the octave note. Count up to B, tune it, then the octave note. Continue — B to E, E to A, A to D, D to G, then check that the Gs are in tune with the Cs — the first notes tuned. They should be. If not, they should only be a little out and you can go back around the loop and make minor adjustments.

All tuned? Now learn to play Bach's Toccata in D minor!

A case

We have not described complete details of a case for this instrument as we would expect constructors to 'customise' a case to suit individual tastes or circumstances. However, we have drawn up the dimensions of a suitable case that may be constructed of 4 mm thick material — such as plastic sheet or plywood. The design has a 'top' and a 'bottom' and each need only be glued together. The board can be mounted in the bottom on standoff pillars. Several standoff pillars screwed onto the board could then support the case top. The accompanying drawings show the rudimentary details. The completed case could be covered in suitably patterned 'Contac', or something similar.

Batteries, supply

The project was designed to be powered by a 9 V battery or other sort of dc supply. It draws around 40 mA at average volume during playing, somewhat over 100 mA at full volume. You can use a No. 216 9 V (transistor radio) battery, but we recommend you get either an extra heavy duty type or an alkaline battery. Alternatively, you could use 6 x AA cells in a 'six pack' battery holder. You can dispense with the battery and use an appropriately rated plugpack if you like. A plugpack rated at 6 V/200 mA will deliver voltages around 8 - 9 V at current loads under 100 mA, and such a plugpack would be the best to use if you want to power the project from the ac mains. ●

OVER 200!

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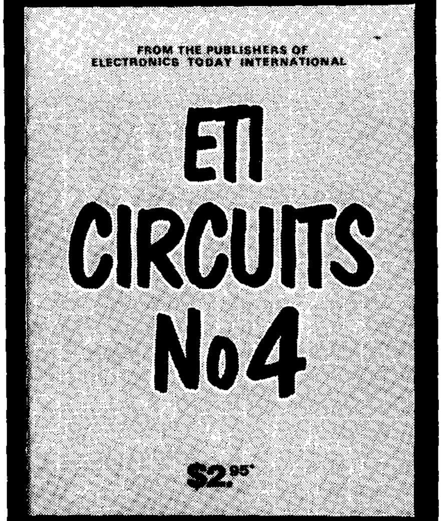
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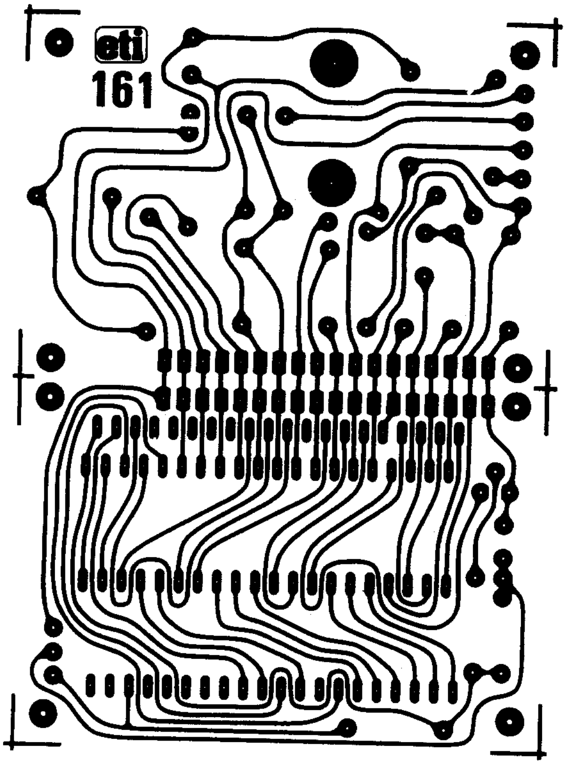
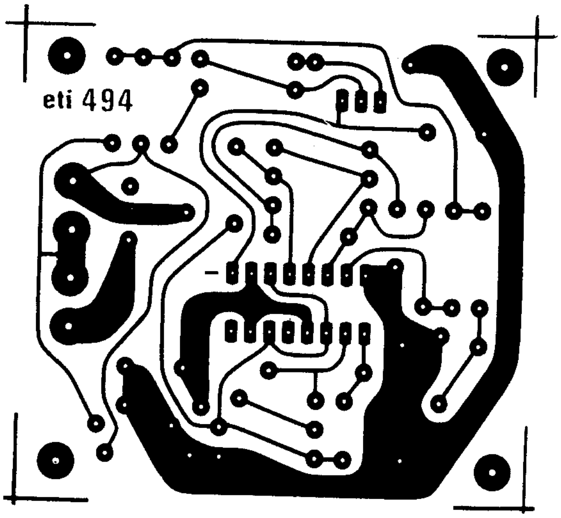
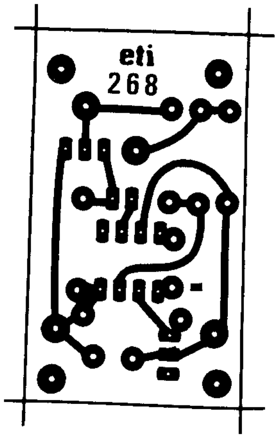
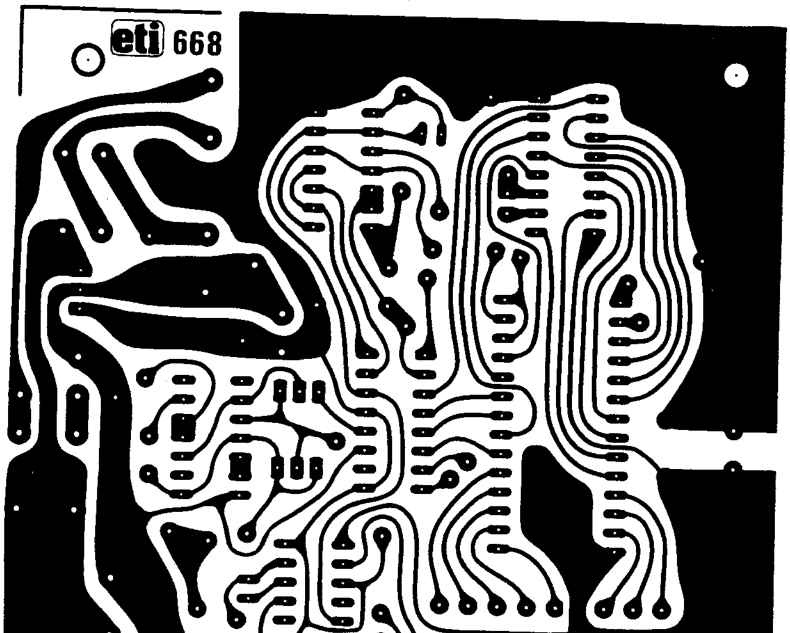
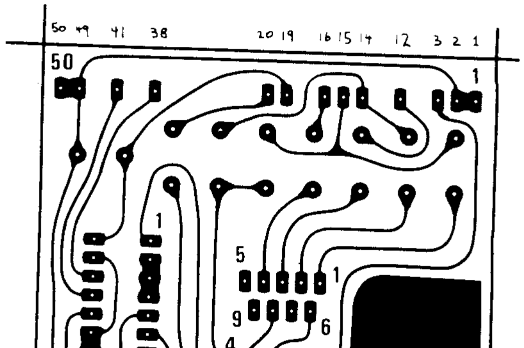


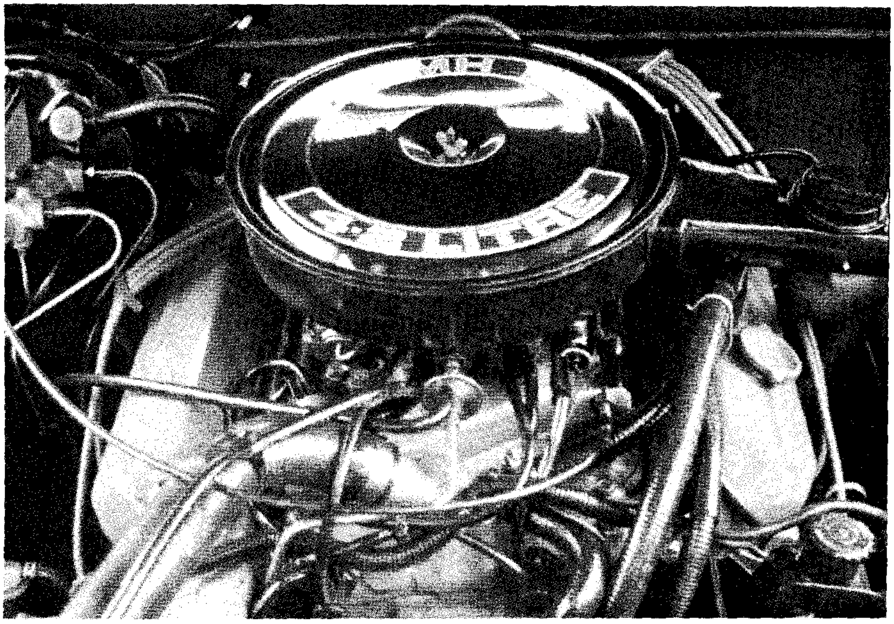








SYSTEM 80 JOYSTICK INTERFACE



The 'Auto Tester'

Graeme Teesdale

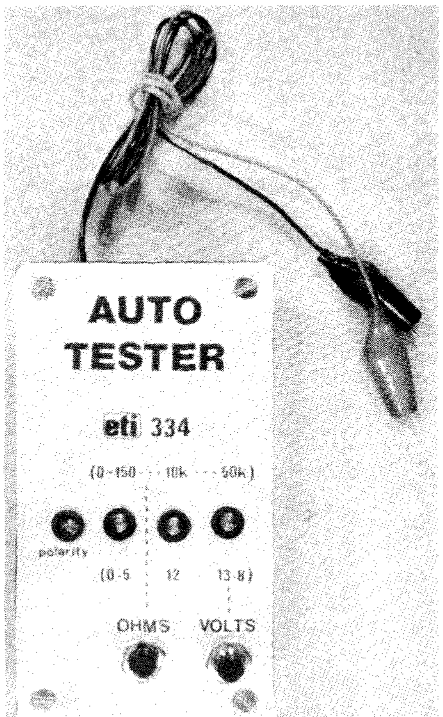
This handy little test gadget will help you sort out all those little bugaboos that can go wrong in automotive electrics. With this, you can check voltage drops, on and off charge battery voltages and resistances.

BUDDING MECHANICS are very often bamboozled by the electrics of a modern motor vehicle. An automotive or electronic type multimeter with its combination scales all crammed together simply adds to the confusion. This project was developed to make fault-finding a little easier by providing simple LED indication of 'set' points in voltage or resistance.

In a vehicle, voltage drop in cables of more than 0.5 volt can bring problems. The Auto Tester provides a clear indication of voltage drops less or greater than 0.5 V. The battery system, to perform up to scratch, must deliver at least 12 V on load and the battery should have a terminal voltage of more than 13.5 V when charging.

Resistances encountered in vehicles tend to have fairly well defined limits. Many devices have resistances under 10 ohms, a few range up to 150 ohms. Thus the first resistance 'set' point is at about 150 ohms. Much higher resistances are encountered in HT suppressors, etc. Generally, these are around 10k or 15k. Trouble can occur if they go faulty and exhibit a high resistance, generally greater than 50k. Thus, two other 'set' points for resistance are at 10k and 50k.

The unit was housed in a small, conveniently-sized jiffy box. The pc board designed for this unit will just fit comfortably into several different types on the market. Four indicator LEDs are provided: a POLARITY indicator, followed by one for each of the three set points in voltage and resistance. Two pushbuttons select which 'mode' you wish to use — VOLTS or OHMS.



Pragmatic. Simple, but functional. The project was housed in a small jiffy box with a Scotchcal panel added.

Where battery polarity is unknown, or in instances where the Auto Tester may be incorrectly connected, the POLARITY LED will light when the red, or positive, input lead is connected to the battery negative.

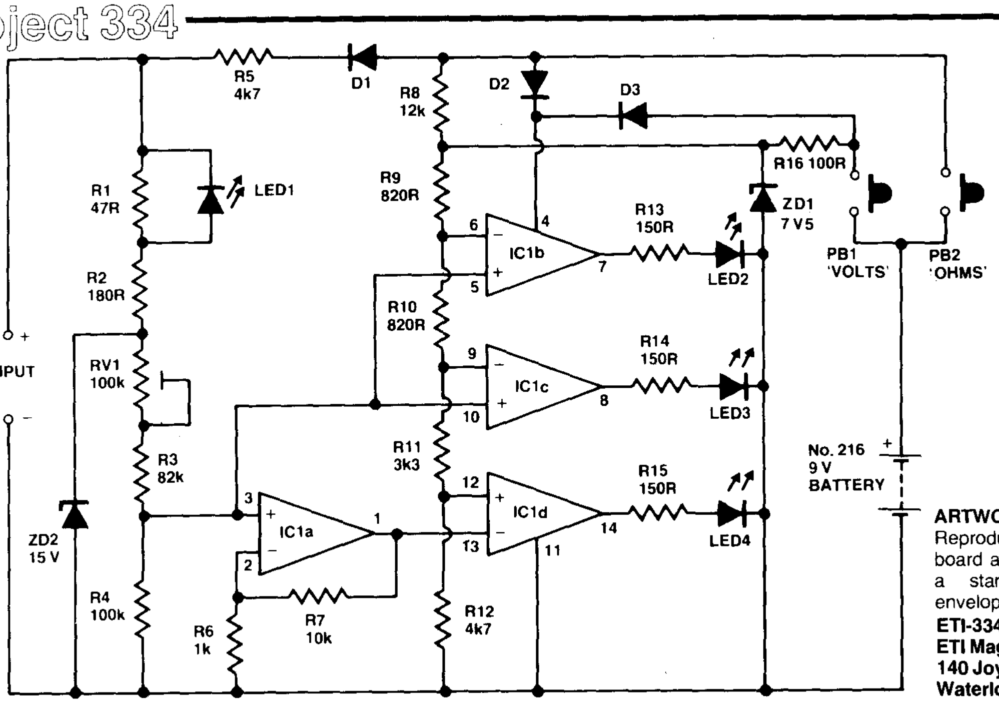
Protection against input overvoltage damage has been incorporated, so that voltage inputs of greater than 15 V are 'clamped' to avoid damaging the IC.

The Auto Tester, unlike most multimeters, will not be damaged if a dc voltage is applied to the input when it is being used in the resistance mode.

The unit is powered from a No. 216, 9 V battery mounted in the jiffy box. The circuit is based around the commonly available, low cost LM324 or uA324 quad op-amp. The battery will likely last its shelf life (probably a year or more) as consumption is only ever momentary, when you take a reading.

Construction

The project pc board has been designed to fit into almost any of the small jiffy boxes available. These are generally all-plastic or plastic cases with a light gauge aluminium 'lid'. We designed a Scotchcal front panel which will suit those boxes measuring 52 x 100 mm or a little larger. ▶



ARTWORK.
Reproductions of the front panel and pc board artwork can be obtained by sending a stamped, self-addressed A4-sized envelope to:

ETI-334 ARTWORK
ETI Magazine
140 Joynton Ave
Waterloo NSW 2017

Before assembling the components to the board, check that is has no breaks or shorts between tracks, particularly between the IC pins. Also check that components like RV1, the zener diodes and LEDs have the correct lead hole sizes drilled. The board can be mounted by soldering the two pushbutton switches directly to the board and letting the board hang from their leads — it's quite a robust arrangement. If you're going to do this, see that the holes in the pc board for PB1 and PB2 are drilled the right size.

Next, check that the pc board fits inside the box. Make sure you orient the board correctly when you do this. If the board doesn't fit in without jamming you may have to carefully trim a little off one or both sides with a file until it fits properly. If it doesn't fit at all, get a bigger box!

Using the front panel artwork, mark out and drill the front panel, or lid, of the box. Fit the four LED mounts.

Once the board is ready to go, commence assembly by soldering all the resistors in

HOW IT WORKS — ETI 334

The clearest way of seeing how this circuit works is to break it down into simplified sections. The Auto Tester performs three main functions: voltage drop measurement, 12/13.8 V measurement and resistance measurement. In addition, an indication of reverse polarity connection is provided along with input overvoltage protection.

The whole circuit is built around an LM324 (or uA324) quad op-amp, IC1. Three op-amps from this are arranged as comparators and one as an amplifier. Let's look at the voltage drop measurement stage first. This portion of the circuit is shown in Figure 1.

Only the relevant components are included. When PB1 is pressed, power is supplied to IC1 via D3. Note that R1, LED1, R2 and ZD2 play no part here. RV1, R3 and R4 form a voltage divider. IC1a is arranged as an amplifier and IC1d as a comparator.

If the input leads are then connected across a cable having a voltage drop of less than half a volt, say 0.2 V, the voltage appearing at the non-inverting input of IC1a will be about 0.1 V (half the input volts) due to the divider action of RV1, R3 and R4. RV1 is set to provide this division ratio of about two. IC1a provides a gain of 10, and thus the output will be 1 V. This is lower than the 2.6 V on the non-inverting input of IC1d and thus its output will be driven high, lighting LED4.

If the voltage drop on the cable you have connected the input leads across reaches a little over a half a volt, say 0.55 V, the voltage on the non-inverting input of IC1a will be 0.275 V. The voltage on the output of IC1a, and thus the inverting input of IC1d, will be 2.75 V which exceeds the 2.6 V on IC1d's non-inverting input. The output of IC1d will thus go low and LED4 will extinguish, warning you of excessive voltage drop in the cable.

Note that, when performing voltage drop measurements, the positive lead must be connected at the end of the cable closest to the positive terminal of the vehicle battery.

When the input leads are open circuit and PB1 is pressed, D1 will be forward biased as it is connected to the 7.5 V rail (from ZD1) via R8. Thus, something a little under 7 V will appear at the 'top' of RV1, and about 3.5 V at pins 3, 5 and 10 of IC1. This will drive the output of IC1d low, and LED4 will be unlit. It won't change the condition of either IC1c or IC1d, so LEDs 2 and 3 will also be unlit. Thus, nothing happens if you press PB1 ('VOLTS') when the leads are not connected to anything.

Let us look at the other voltage measurements now. This section of the circuitry is shown in Figure 2. IC1b and IC1c are connected as comparators. Each has their inverting input connected to the voltage divider R9, 10, 11 and 12. This voltage divider is supplied from a regulated 7.5 volts, derived by ZD1 and R16. Thus, battery voltage variations will not affect circuit operation, provided the battery voltage doesn't fall to about 8 V or less. IC1b and IC1c have their non-inverting inputs connected together and these are attached to the input voltage divider.

Figure 1. Voltage drop measurement.

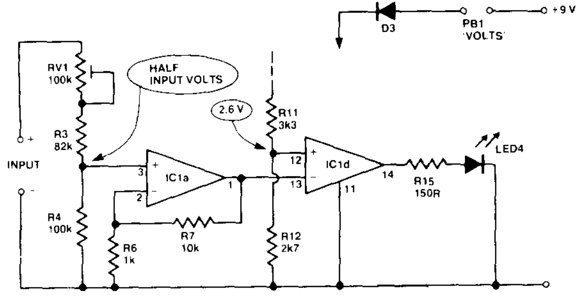
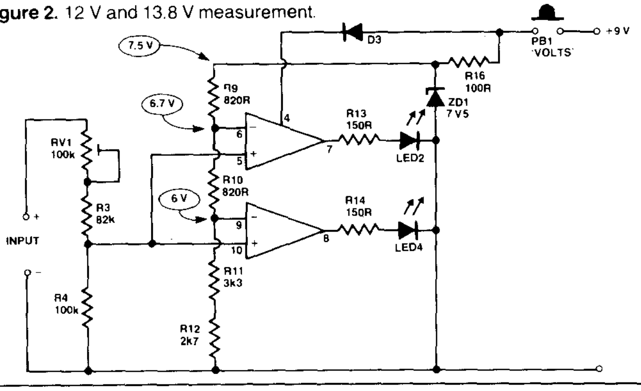
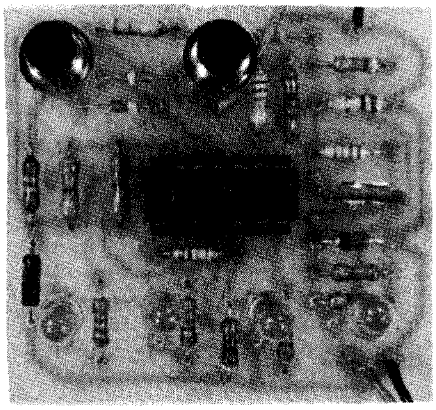


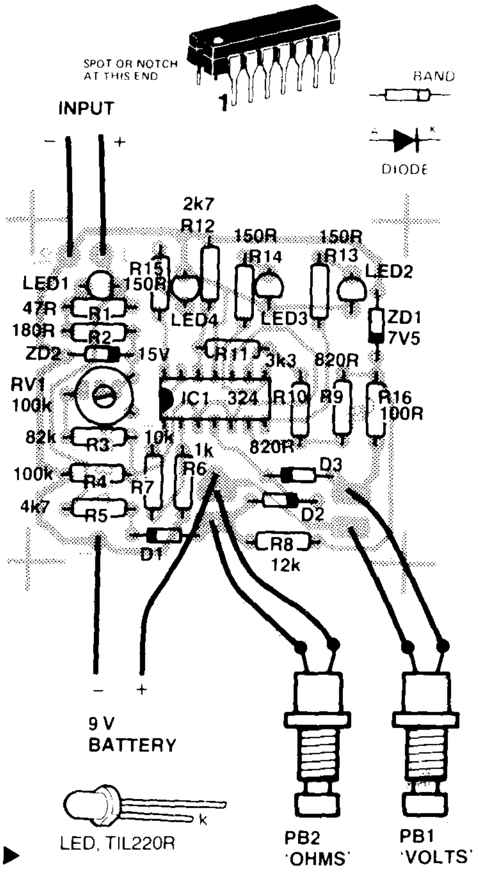
Figure 2. 12 V and 13.8 V measurement.





place, then the diodes D1, 2 and 3, followed by the two zener diodes. Make sure you get all the diodes in the correct way round.

If you're mounting the board to PB1 and PB2, solder these in place now, making sure their mounting 'shoulders' are level. Insert the four LEDs next, but don't trim them in place. Make sure you orient them correctly and don't trim off their leads. Temporarily mount the board to the front panel of the case. Push the LEDs into position and then solder and trim their leads. De-mount the board from the panel and fit IC1, RV1, the battery clip lead and the two input leads. ▶



PARTS LIST — ETI-334

Resistors	all ¼W, 5% unless noted
R1	47R
R2	180R
R3	82k
R4	100k
R5	4k7
R6	1k
R7	10k
R8	12k
R9, R10	820R
R11	3k3
R12	4k7
R13, 14, 15	150R
R16	100R
RV1	100k min. trimpot, horizontal or vertical mount.
Semiconductors	
D1, 2, 3	1N914, 1N4148 etc
IC1	LM324, uA324
LED1, 2, 3, 4	TIL220R red LEDs
ZD1	7V5 zener diode
ZD2	15 V zener diode
Miscellaneous	
PB1, PB2	press-on pushbutton switches

ETI-334 pc board; jiffy box 52 x 30 x 100 mm or thereabout; No. 216 battery and battery clip lead; two alligator clips and leads, one red, one black; Scotchcal front panel, etc.

Price estimate $15 — $17

When PB1 is pressed, power is supplied to IC1 via D3, as before. With no input voltage, the outputs of IC1b and c will both be low and LEDs 2 and 3 will be unlit. When the input leads are connected to a voltage a little over 12 V, the voltage on pin 10 of IC1c will be a little over 6 V. This will drive the output of IC1c high, lighting LED3. When the input voltage rises above about 13.5 V, the voltage on the pin 5 of IC1b will be a little over 6.7 V, driving the output of IC1b high, now lighting LED2 also.

Look at resistance measurement now. For this explanation, refer to the complete circuit diagram. As before, R1, LED1, R2 and ZD2 play no part here.

When PB2 is pressed, power is supplied to IC1 via D2. Some current is supplied to the resistive divider network, R9-10-11-12, by R8. This establishes a different set of voltages on the three comparator inputs. Pin 6, IC1b will now have about 3.8 V on it, pin 9, IC1c about 3 V on it and pin 12, IC1d about 1.3 V on it.

When the leads are connected to a resistance, current will be supplied to the resistance via D1 and R5. Say the resistance is 100 ohms. About 1.8 mA will be driven through it because there is about 8.5 V on the cathode of D1 and 8.5 divided by 4800 ohms gives about 1.8 mA. Thus, there will be a voltage drop across the 100 ohms of resistance of about 0.18 V. About 0.09 volts will appear on pin 3, IC1a. The output of IC1a will drive the inverting input of IC1d to about 0.9 V which is less than the 1.2 V on IC1d's non-inverting input. Thus the output of IC1d will be high, lighting LED4. If the resistance across the input is say 180 ohms, the voltage across the input leads will be about 0.32 V. About 0.16 V appears on pin 3, IC1a and 1.6 V on pin 13, IC1d. The output of IC1d will therefore go low, and LED4 will not light.

If the resistance across the input terminals is between 150 ohms and 10k, say 5000 ohms or so, then the voltage across it will be about 4 V. The voltage on pin 10, IC1c will be about 2 V, which is less than that on pin 9 and the output of IC1c will be low and LED3 will be unlit. If the resistance across the input leads is about 15k, say (such as a spark plug suppressor resistor), then the voltage across the input will be about 6.4 V and the voltage presented to pin 10, IC1c will be about 3.2 V. This is above the 3 V on pin 9 and the output will thus go high, turning on LED3.

If the resistance across the input leads is about 50k, then the voltage across the input will be about 7.8 V. The voltage on pin 5, IC1b will be about 3.9 V and the output of IC1b will therefore be high, turning LED2 on. Note that LED3 will also be on as the voltage on pin 10, IC1c is above that on pin 9 and IC1c's output will be high also. Thus, for all resistances above 50k (including an open circuit) LED2 and LED3 will light.

Followed that so far? Alright, let's look at the reverse polarity indication. The relevant portion of the circuit is shown in Figure 3.

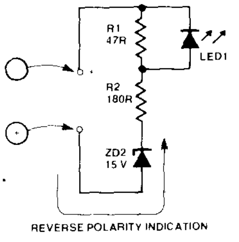


Figure 3.

REVERSE POLARITY INDICATION

If the input leads are transposed while trying to measure voltage, ZD2 will conduct as a diode in the forward direction (as shown by the arrow), passing current through LED1, which will turn on. It will also pass some current through R1, but that's immaterial. R1 is there so that current can pass to RV1 when the leads are correctly connected, otherwise no current would pass through LED1 as it would appear as a reverse-biased diode.

If you reverse the input leads while attempting to measure voltage drop, LED1 will only come on if the voltage drop is above about 1.3 V or so. Thus, it is important to watch lead polarity when measuring voltage drop in cables.

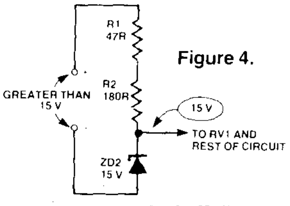
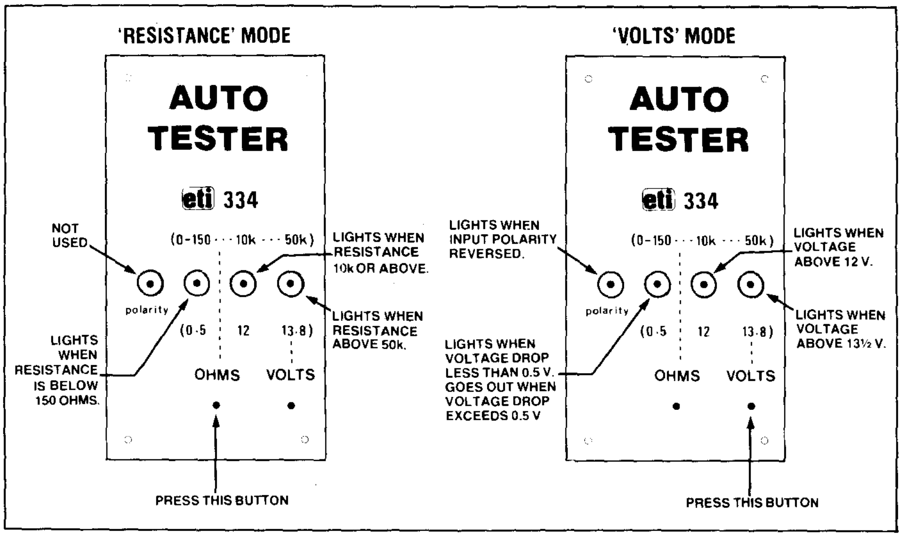


Figure 4.

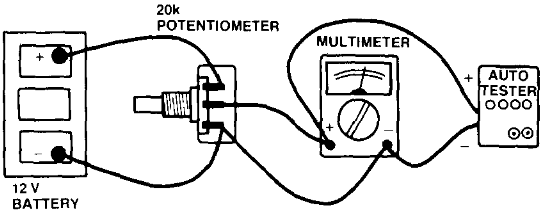
OVERVOLTAGE PROTECTION

Overvoltage protection is provided by ZD2. Why have it? Well, if a battery cable comes adrift and you're attempting to measure voltages while the motor is running the generator/alternator can quite easily deliver outputs of 20 V or so. This can possibly destroy the LM324. In addition, it is not unusual to get inductively-produced voltage 'spikes' on the supply lines in a vehicle, which can also destroy the IC. If a voltage of greater than 15 V appears on the input leads to the Auto Tester, ZD2 will ensure that the voltage delivered to the LM324 does not exceed 15 V.

The various voltages and resistances given here can vary by +/− 10% or so without grossly affecting your interpretation of readings. What you are after, after all, is 'ballpark' measurements which will indicate if all is well, or not.


'RESISTANCE' MODE
AUTO TESTER
eti 334
(0-150 ··· 10k ··· 50k)
polarity
(0·5 12 13·8)
OHMS VOLTS
NOT USED
LIGHTS WHEN RESISTANCE IS BELOW 150 OHMS.
LIGHTS WHEN RESISTANCE 10k OR ABOVE.
LIGHTS WHEN RESISTANCE ABOVE 50k.
PRESS THIS BUTTON
'VOLTS' MODE
AUTO TESTER
eti 334
(0-150 ··· 10k ··· 50k)
polarity
(0·5 12 13·8)
OHMS VOLTS
LIGHTS WHEN INPUT POLARITY REVERSED.
LIGHTS WHEN VOLTAGE DROP LESS THAN 0.5 V. GOES OUT WHEN VOLTAGE DROP EXCEEDS 0.5 V
LIGHTS WHEN VOLTAGE ABOVE 12 V.
LIGHTS WHEN VOLTAGE ABOVE 13½ V.
PRESS THIS BUTTON

Now you're ready for testing. But first, check *everything* carefully. See that the IC, all diodes and LEDs are correctly orientated, according to the component overlay.



Calibration. Test setup for calibrating the Auto Tester.

Testing the unit

Fit a 9 V, No. 216 battery. Short the input clips together and press the VOLTS button. The 0.5 V LED should come on. If not, check component orientations, then resistor values. Fix any faults. Once you have that corrected, try again. When you get the 0.5 V LED to light, unclip the input leads and it should go out.

To calibrate the unit, you'll need to get hold of a multimeter, a well charged 12 V battery and a 20k potentiometer. Hookup the circuit shown here and adjust the potentiometer to give a 12 V reading on the multimeter. Press the VOLTS button and adjust RV1 so that the '12 V' LED just lights. Then, reset the potentiometer to get a 0.5 V reading, or a little more, on the multimeter. The '0.5 V' LED should just light. If it doesn't light, vary the potentiometer slightly until it lights. If the '0.5 V' LED lights when the multimeter reads more than ±0.1 V from 0.5 V, then you may have to change the value of R12. Increase it if the voltage is low, decrease it if the voltage is high. Just take the next highest or next lowest resistor value, you're only after a 'ballpark' indication, after all.

Set the potentiometer fully 'up' (fully clockwise). If the battery is well charged, then the multimeter should read 13.5 V or above and the '13.8 V' LED should turn on, along with the '12 V' LED. Now, reverse the Auto Tester input leads. The POLARITY LED should come on.

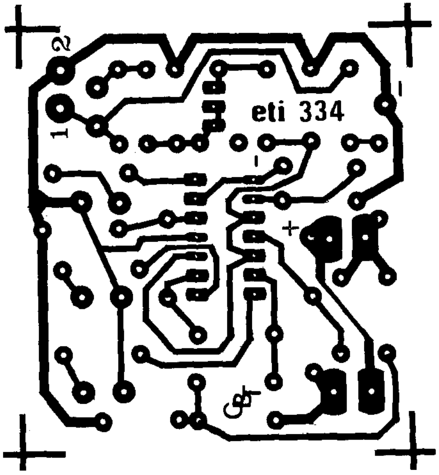
If you can't get the proper indications, check with the multimeter that you are getting 7.5 V (within ±0.3 V) across ZD1 when you press the VOLTS button. Also check the voltages on pins 6, 9 and 12 of IC1 when you press the VOLTS button and see they are close to those given in the How It Works.

If all is well, proceed with testing the OHMS mode. Disconnect the 12 V battery. Set the multimeter to read resistance (should be the X1 scale). Adjust the potentiometer until the multimeter reads about 100 ohms. Press the OHMS button and the '0-150' LED should come on. Turn the potentiometer until that LED goes out and keep turning till the '10k' LED turns on. It should turn on when the multimeter reads somewhere in the vicinity of 10k.

With the Auto Tester leads open circuit, both the '10k' and '50k' LEDs should turn on.

You are now ready for use. Happy fault-finding! ●

Full size pc board artwork.



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An EPROM programmer for the MicroBee

This simple, low cost EPROM programmer just plugs into the MicroBee's I/O port and enables you to save programs in any of five different common EPROMs which can then be used in your MicroBee or any other microprocessor-based system. As the MicroBee I/O port is effected with a Z80 PIO chip, this programmer can be used with any other system employing the same I/O.

Tom Moffat
Geoff Nicholls

SICK OF loading tapes? Well here's a way to avoid much of the drudgery, at least for your favourite machine code programs. EPROMs — Eraseable Programmable Read Only Memories — are a storage medium often overlooked by keen computerists intent on blowing big dough on such things as disk drives. Information in EPROMs is the same as in any other read only memory ... it's always there, and instantly available when you switch on the computer.

It would be fair to say that probably 99% of all EPROMs are programmed once and then forgotten. Manufacturers of computers in small production runs, that is by thousands instead of millions, find it convenient to put their 'firmware' in EPROMs, instead of mask-programmable ROMs. It's cheaper in small quantities, and they can do the programming themselves, instead of having a chip manufacturer make up a special (and expensive) mask.

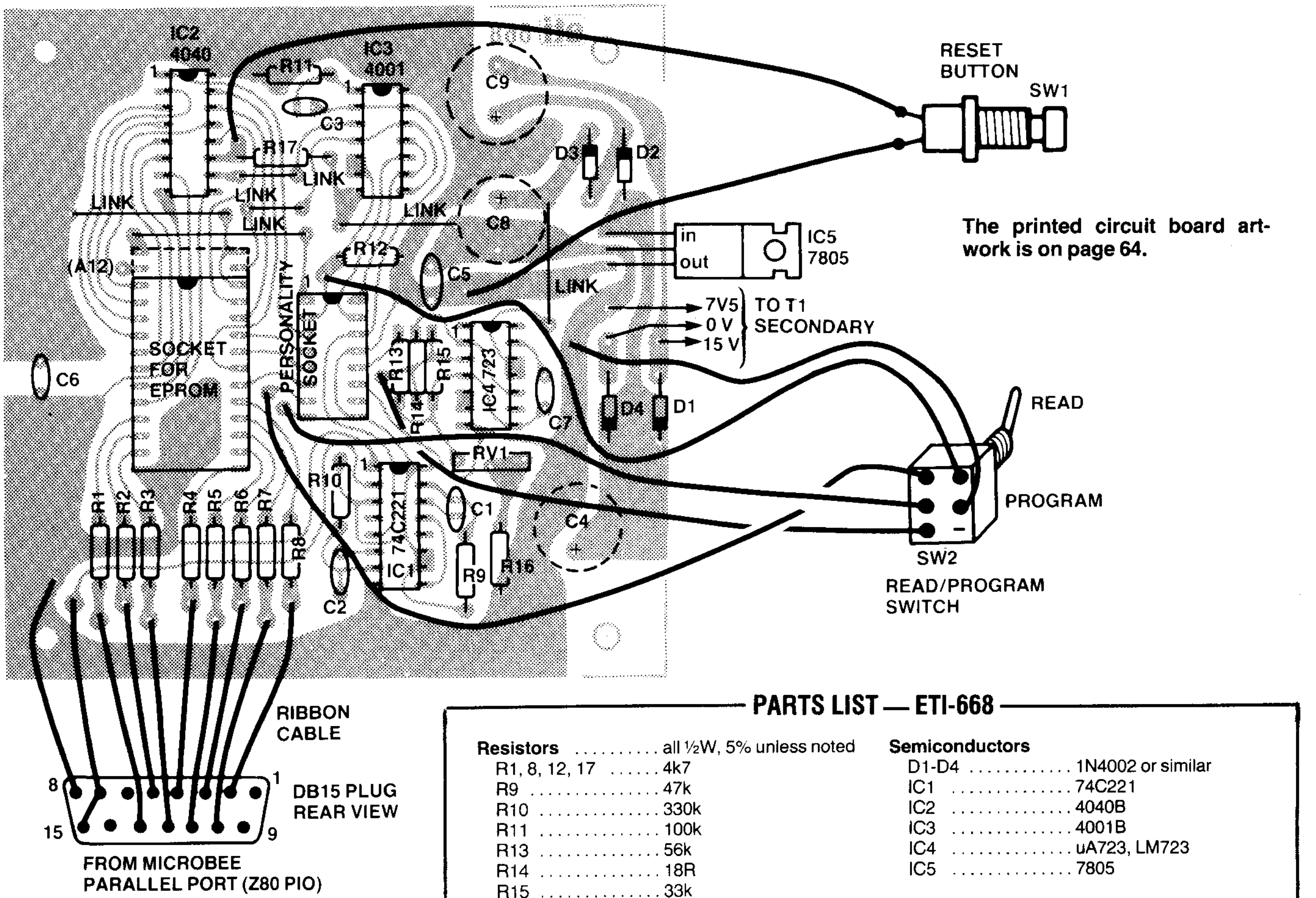
The standard MicroBee has four EPROMs containing its 16K BASIC, and there are two more if the Editor/Assembler is fitted. There's another blank position meant for a future networking EPROM which can be put to use for other purposes with the help of this project.

A version of this programmer has been in use for over two years, connected to a 6800-based computer that I built. Giving credit where credit is due, what was laughed at by some as a 'toy computer' has turned into a highly useful tool, especially since an upgrading in the EPROM department.

It started out with a 1K byte EPROM which was exchanged for a 2K 2716 and then a 4K 2732, a change which required only two jumpers to be moved. The original 1K of machine code now resides in the bottom quarter of the 2732. Within the other three-quarters of the EPROM are a debugging routine, a branch offset calculator, a branch address calculator, a disassembler, hex memory dump to teletype, and teletype printing programs for the Tandy/Sharp pocket computer and the MicroBee. And there's nearly 1K still free!

All this software started off small and just grew until most of it is now interlinked, with some programs accessing subroutines in maybe two or three others.

The point of all this is that there's an empty EPROM slot in the MicroBee that's just *begging* to be filled with a 2532. And Z80 versions of the above mentioned software ▶



The printed circuit board artwork is on page 64.

PARTS LIST — ETI-668

Resistors .... all ½W, 5% unless noted

R1, 8, 12, 17	4k7
R9	47k
R10	330k
R11	100k
R13	56k
R14	18R
R15	33k
R16	15k
RV1	4k7 min. vertical mount trimpot

Capacitors

C1, C3	1n greencap
C2	100n greencap
C4	470u/16 V RB electro.
C5, 6, 7	100n ceramic bypass
C8	470u/50 V RB electro.
C9	470u/25 V RB electro.

Semiconductors

D1-D4	1N4002 or similar
IC1	74C221
IC2	4040B
IC3	4001B
IC4	uA723, LM723
IC5	7805

Miscellaneous

SW1	push-to-close single pole pushbutton
SW2	two-pole, double throw toggle switch
T1	2155, 15 V/1 A multi-tapped transformer

ETI-668 pc board; 16-pin DIL socket and set of plugs or DIP headers; 24-pin DIL socket (or a ZIF socket if desired); Jiffy box — 60 x 113 x 196 mm; hookup wire, nuts, bolts, etc.

Options for 2764s **Delete** 24-pin DIL skt
add 28-pin skt
add SPDT toggle switch
add 4k7 resistor

Price estimate **$40 — $45**

could very well fill the EPROM. The same goes for any machine code. (Your favourite game?) It's also claimed that 2716s are pin-compatible with the MicroBee's 6116 RAMs, and if yours is a 16K MicroBee there are eight 6116 slots empty. This hasn't yet been tried and should be approached with caution as it could be disasterous to the 6116 battery backup system.

The hardware

EPROM programmers seem to come in two different types — complicated, and with the arrival of the ETI-668, not so complicated. You could simply go out and buy one, paying hundreds of dollars. Computer-driven home-brew models usually require all 16 address and eight data lines to be brought out, or lots of parallel in/out ports. The MicroBee only has one parallel port. The ETI-668 does the job with one port, an on-board address generator, an on-board programming pulse generator, and a 'trigger pulse'.

The computer first presents a byte of data to the EPROM via the parallel port's eight data lines and then supplies the trigger pulse via the port's handshake lines. The trigger pulse sets off a 50 ms single-shot multivibrator to form the programming pulse, and as the programming pulse finishes it increments the address generator.

The trigger pulse is officially meant to tell a printer to print or a punch to punch, so it applies only to data leaving the computer. But what happens when you want to read material from the EPROM into the computer? If you believed the data books you'd give up at this stage, but now comes the incredible story of *the illegal trigger pulse*.

My 6800 machine uses Motorola's 6821 parallel port chip which can be programmed to provide a trigger pulse via its CB2 handshake line whenever data is sent out. But, wonder of wonders, the pulse occurs even when the port is configured as an input. Data written to it doesn't go anywhere but the act of writing does fire the trigger pulse. So, the trick is to read the port to get a byte from the EPROM, and then write a dummy value back to it to increment the address generator.

Discovering that bit of undocumented information was an unexpected stroke of good luck, but you haven't yet heard the best of it. The MicroBee uses the Z80 PIO chip for its parallel port, a device as different from Motorola's 6821 as night is from day. Would the same trick work again? The gods must have really been smiling.

The PIO data sheet shows that when the chip is configured for output, and with the handshake lines 'ready' and 'strobe' tied together, a half-microsecond positive-going pulse comes from them after an 'OUT' instruction to the port. Once again, outputs only. So what would happen with the port set up as an input? Yep ... one undocumented, illegal trigger pulse! How can this happen to me, I've never even won a miserable 50 cent sweep? Perhaps we should shut up and be thankful to that great chip-designer in the sky.

With that handy trigger pulse available it's now an easy matter to program and read EPROMs with a simple circuit.

Now a few words about the quirks of EPROMs from someone who blew up several during the development of this project.

Each bit in an unprogrammed EPROM is high, so all bytes read 'FF'. During programming each bit required to be low is hit with what amounts to a miniature lightning bolt. If the hit is too long, or too powerful, *Ka-boom* — one blown EPROM.

The supply for properly 'burning' an EPROM comes from a 'high voltage' regulated source, usually 21 or 25 volts. With normal programming, an EPROM draws less than 30 mA from this supply. When something goes wrong, it draws much more, usually resulting in the absolute destruction of the EPROM. With that in mind, the 'programming' supply for this project has a current limit protection of 30 mA designed in.

Many programmer designs let the computer develop the 50 ms programming pulse in software. The ETI-668 does it with a hardware single-shot, nice and foolproof, even if the computer program crashes for some reason. A characteristic of EPROMs often ignored is the specification that the data lines must settle down for at least four microseconds before the programming pulse begins, and another four microseconds must be allowed between the end of the programming pulse and any changes on the address lines. This design provides 50 microsecond delays — much longer than necessary, but easy to see on an oscilloscope when setting up the programmer board.

The barbershop blues

EPROMs are erased by exposure to ultraviolet light. You can go out and buy a special EPROM eraser for many dollars. A UV tube costs about $20. But, if you know a friendly barber your outlay will be nothing more than an occasional haircut. Most barber shops have a device called a 'Servex Ultraviolet Sterilizer' for getting the nasties out of combs and brushes. A half hour in the old Servex will erase an EPROM nicely, and give you and the barber something to talk about besides cricket or football.

Construction

Before we start, a couple of things need to be pointed out. Firstly, for the majority of hobbyist applications the expense of a zero insertion force socket seems unjustified. A better choice would be one of the better quality 'normal' IC sockets, such as the ones with gold-plated pins. I have used one of these in my programmer board and in the spare EPROM position in my MicroBee and both will have EPROMs plugged in and out fairly frequently. (However, the ETI-built version, shown in the photographs, has a ZIF socket soldered in place as we plan to use the programmer rather more frequently than most hobbyists — Ed.)

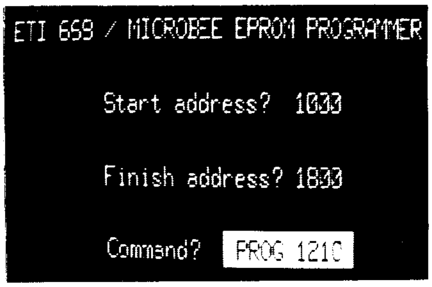
Secondly, if your MicroBee isn't equipped with a port socket (DB15 female, pc mount style), now's the time to install it. (Editor's note: our MicroBee 64 had the DB15 port socket shown back to front on the pc board silk screened overlay — just check this if you're installing your own socket.)

Assembling the pc board is fairly straightforward. Before commencing assembly, have a good look at the pc board and make sure that no tracks are broken or shorted together. This applies especially if you are making your own pc board. If the visual check is OK, start by soldering the five links in place. These have been included despite the fact that they're often considered 'bad form'. But the few links are preferable to a more expensive double-sided board, just for the sake of a few connections.

Mount all the resistors and capacitors next, with the exception of the three power supply electrolytics, C4, C8 and C9. These can be mounted either on top of the board or, as in the ETI prototype, under the board. The latter course of action enables you to mount the board beneath the front panel of a jiffy box, or other suitable enclosure. If you just intend to have the unit 'hanging around on a shelf or in a drawer', then the electrolytics may be mounted on the top (non-copper) side of the board. For the sake of convenient handling, leave the mounting of the electrolytics till last.

The diodes and ICs can be mounted now. Take care with the orientation of the diodes. ICs 1, 2 and 3 are CMOS types and the usual handling and soldering precautions should be observed. Only handle them between thumb and forefinger, avoid touching the pins, and solder the supply pins first. IC4 is a conventional bipolar IC and no special precautions need be observed. Note that ICs 1 to 4, the personality socket and the EPROM socket are all aligned so that they face the same direction. IC5 is a three-terminal regulator. This mounts with the metal tab facing toward the board. Now you can mount the 16-pin personality socket (an ordinary IC socket) and the 24-pin or 28-pin socket for the EPROM.

Attach suitable lengths of hookup wire to the board and wire up the reset button, SW1, and the read/program switch, SW2. Check it when you've finished. Next strip a short length of ribbon cable so that you have ten wires. Peel back the wires individually at each end, strip and tin the ends, then wire one end to the pc board and the other end to the DB15 plug as shown in the overlay. Carefully check that you have the plug correctly wired.



```
ETI 668 / MICROBEE EPROM PROGRAMMER

Start address?  1000

Finish address? 1800

Command? PROG 121C
```

Now you can mount the electrolytics, C4, C8 and C9. If mounting them on the copper side of the board, leave about 4 mm space between the board and the bottom of the component so that you can reach the leads with the soldering iron.

Wire up a set of personality plugs as shown in the accompanying diagrams. It's a good idea to stick a label to each DIP header before you attach the wires.

Now you can wire up the mains transformer, after which you're ready to check out and set up the programmer.

Check out and set up

For this you'll need a good multimeter. For absolute accuracy in setting up the programming pulse, you'll need access to either an oscilloscope or a counter-timer. Nothing fancy as you're only looking at 50ms +/− a bit pulses. There's a 'fudge' setup method too, where you don't need these instruments.

First off, set the read/program switch to 'read'. Don't put anything in the personality socket or the EPROM socket.

Connect up the mains and switch on. Quickly check the output voltages from the two rectifiers. You should get around 30 V at the cathode of D3 and around 10 V at the cathode of D1 (or D4). If not, switch off and check your transformer wiring and diode orientation. If those voltages check out, measure the output of IC5 (the 7805). It should be 5V, ±0.2 V. Now you can set up the programming voltages.

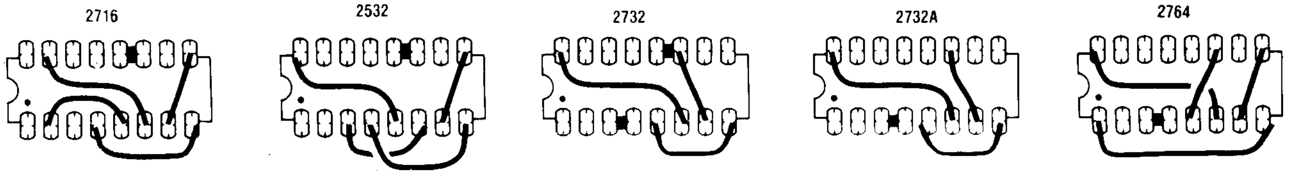
Measure the voltage between pins 7 and 3 (positive lead to 3) of IC4. Vary RV1 so that you get 21.0 V. Then put a 2716 personality plug in the personality socket. Now, again measure the voltage between pins 7 and 3 of IC4. It should now be 25 V, ±0.5 V.

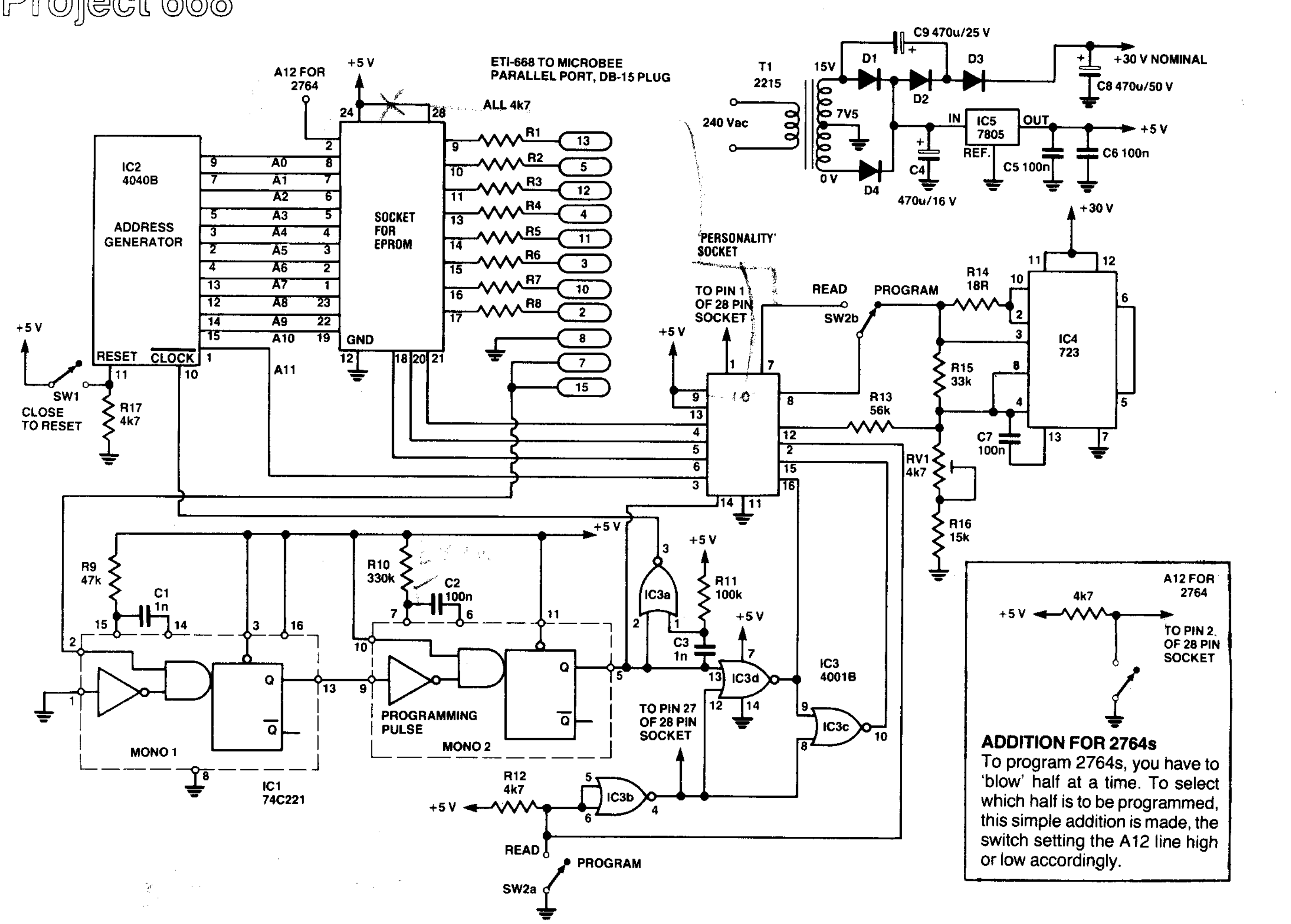
Next thing to do is check the programming pulse width.

There are two ways you can go about this — using the instrumental method or the 'fudge' method.

If you have access to a CRO or counter-timer, plug the programmer into the MicroBee and run the software. Nothing should be plugged into the EPROM or personality sockets. Look at pin 5 of IC5 (it doesn't matter if you're 'programming' or 'reading'). The pulses there should be ▶

'PERSONALITY' PLUGS





ADDITION FOR 2764s
To program 2764s, you have to 'blow' half at a time. To select which half is to be programmed, this simple addition is made, the switch setting the A12 line high or low accordingly.

HOW IT WORKS — ETI-668

This project is designed to be used with one port of a Z80 PIO (Parallel Input/Output chip) as one is used on the MicroBee for the parallel port. Any other microcomputer employing a similar scheme could use this project. This port supplies the data to the EPROM inserted in the programmer board through resistors R1 to R8 which prevent damage in the event of write conflicts. The READY and STROBE lines of the port are tied together to produce a half-microsecond positive-going pulse whenever a read or write operation is performed. This pulse, after a 50 us delay through MONO 1 (from IC1) is used to clock the program pulse generator, which is MONO 2 from IC1. IC1 is a 74C221, a CMOS dual monostable IC. The program pulse should be 45 to 55 milliseconds long and is determined principally by R10 and C2.

The READ/PROGRAM switch, SW2a, is gated with the program pulse to produce the various signals required by different types of UV-erasable EPROMs.

The signals available at the 16-pin 'personality' socket are routed via a programming (or personality) plug to suit the EPROM being programmed. The plug wiring details for five types of common EPROM are shown elsewhere in the article.

IC2, a 4040, generates the address lines for EPROMs up to 4K bytes. It is clocked by the falling edge of the program pulse. To program 8K byte EPROMs an extra switch is required to develop the A12 address line. The switch wiper should be connected to pin 2 of the 28-pin socket and should switch to +5 V or 0 V to select the upper or lower 4K bank, respectively. Closing SW1 effects a RESET of the address generator.

The power supply combines a fullwave rectifier and a voltage tripler to develop the two supplies necessary. Transformer T1 has a 15 V centre-tapped secondary. A fullwave rectifier, consisting of D1, D4 and C4 provides around 10 V for a 7805 three-terminal regulator which derives a +5 V rail for the ICs. A programming voltage of either 21 V or 25 V is required by some EPROMs. A voltage tripler, involving the addition of diodes D2 and D3 and capacitors C8 and C9, develops a nominal 30 V. A 723 precision regulator, IC4, regulates the required programming voltage (Vpp) of either 21 V or 25 V. Output from the 723 is from pin 10, via R14, which limits the short circuit output current to 30 mA. The voltage divider comprising R15, RV1 and R16 establishes an output of 21 V when RV1 is properly set. If pins 11 and 12 of the personality socket are shorted together, R13 is placed across RV1-R16, raising the 723's output to 25 V.

Switch SW2b selects the voltages applied to the Vpp input of the EPROM inserted in the programmer. Note that 2732s and 2732As require 0 V during read while other EPROMs require +5 V.

between 45 and 55 ms wide. If not, change the value of either R10 or C2 to bring the pulse width within these limits. Note that the value of R10 should not be greater than 330k. While you're at it, just check that the pulses on pin 13 of IC1 are around 50 us or so. This pulse width can have considerable latitude as the minimum required is 4 us.

The fudge method requires a ready-programmed EPROM. Set up the programmer and software to read the EPROM. If the pulse from Mono 2 (IC1) is too long, the first byte will be read correctly, the next byte will read the same as the first byte, the third byte will be read correctly, the fourth byte will read the same as the third ... etc. Change C2 or R10 down by one standard value (i.e: C2 to 82n *or* R10 to 270k) and try again.

If you read the EPROM correctly first go, vary the byte at 0ECF in the control program, reducing it from 10 to 0E, then 0D etc, until the result of a read is the same as if the pulse from Mono 2 were too long (every second byte reads the same as the previous byte). If the pulse from Mono 2 is within limits, you should get a correct read from the EPROM when the byte at 0ECF is between 0D (lower limit) and 12 (upper limit). Increase the value of C2 by one standard value (to 120n) and try again if it's outside these limits.

Software and programming

Although the control program looks long and involved, the actual machine code used by the computer is only 422 bytes long, small·

enough to be typed in by hand. Most of the code is involved with the screen display. The EPROM routines themselves are very short.

A feature of the program is its ability to partially program an EPROM, step over existing material and then add new stuff. This avoids lots of unnecessary erasures. It would have been simple to arrange the program so that stepping, programming and verifying happened automatically following a set of predetermined instructions. But, following past experience, it was decided to allow manual operation only ... you specify each action as it happens.

The purpose is to make you think. Are the addresses right? Do I really want to program, or just step? The screen display has been organised to make this quite easy.

When run, the program will show a title and then ask for a 'start address'. You must enter four hexidecimal (hex) digits, including any leading zeroes. You put the MicroBee keyboard into alpha lock for entering hex code. When you've done that, the program then asks for a 'finish address'. You enter more hex digits and the program then asks for a 'command'. You now double-check the addresses to ensure they point to the material you want to work on. If there's a mistake, you hit 'break' and the computer asks you for the addresses again. If all is OK, you now enter your command, using two hands to prevent mistakes. One for the control key, and one for a letter, as follows:

P = program from memory into EPROM
R = read from the EPROM into memory
S = step to a new address
T = test that the EPROM area is erased
V = verify that it all worked.

'PERSONALITY' SOCKET PIN DESIGNATIONS

				prog.	read
1.	Vpp INPUT (2764)	16.		⊔	—
2.	READ/PROGRAM	15.		⊓	—
3.	A11	14.	PIN 5 IC1		
4.	PIN 21	13.	+5 V		
5.	PIN 20	12.	CONNECT TO 11 FOR 25 V		
6.	PIN 18	11.	GROUND (0 V)		
7.	READ Vpp SELECT	10.	NOT USED		
8.	Vpp	9.	+5 V		

A white bar now appears on the screen, showing you what you're doing and in what area of memory. The memory locations roll along like a digital speedo in a car. In the event of an error, either from the erasure test or the verify routine, an appropriate message is displayed, telling you your EPROM has just earned a trip to the barber shop!

There are a few other manual operations involved. Before attempting to program an EPROM, make sure the programmer is turned on. If it isn't, you could damage an EPROM if you then attempt to program it. There are two good tricks to ensure you've done the right thing here. Install a 'piggy back' plug on the mains power lead to the programmer. When using the programmer, plug it into the power socket in the wall then plug the MicroBee's plugpack into the piggy back plug. You could also wire a 12 V bezel lamp across the 10 V supply. With the programmer plugged in and turned on, the *first* thing you must do is operate the RESET pushbutton, SW1, to initialise the EPROM address generator, setting the EPROM address to zero. Before issuing a program instruction, the read/program switch, SW2, must be in the WRITE position. You must return SW2 to the READ position after programming.

To ensure you don't make a mess of your EPROM it's best to get a pencil and paper and write down, step by step, exactly what you intend to do. As an exercise, let's say we want to put a program called 'Crash' into our EPROM that lives at the spare location E000. (This and all further addresses will be in hexidecimal notation.) There is already a debugging routine in the EPROM at E000-E0FF. We will assume the rest of the EPROM is empty. Here's how we do it:

We must first assemble the program to run in its eventual destination, but we'll have to physically put it somewhere else so it can be programmed into the EPROM. The MicroBee assembler has an 'offset' feature which allows us to do this.

'Crash' must start at E100, the next byte up from the end of 'Debug'. The normal place to put freshly assembled code is at 0400, so we'll assemble with an offset of 2300. After assembly we find that the last byte of 'Crash' will be at E2FF. Note that, the 'finish address' has to be *one byte more* than the last byte of the program to be entered. Thus, when loading, 'Crash', the finish address is E300.

Turn on your MicroBee and programmer and put SW2 at READ. Then plug the DB15 connector into the MicroBee port. Load the EPROM program and insert the EPROM to be 'burned' into the socket on the ETI-668. Now we go to our pencil and paper:

1) Press SW1 to reset the EPROM address counter. (Is SW2 at READ?)
2) Step E000-E100. (Steps over 'Debug'.)
3) Test E100-E300. (Erased?)
4) Press SW1 again. (RESET address counter.)
5) Step E000-E100.
6) Switch SW2 to PROGRAM.
7) Program 0400-0600. (Have faith, dear fellows ...)
8) Switch SW2 to READ, again.
9) Press SW1 again.
10) Verify E000-E100. (Is 'Debug' still OK?)
11) Verify 0400-0600. (Is 'Crash' OK?)

Did the white bar stop at 0600? Good. Error message? The number on the white bar will say where the error occurred, if you get one, a fact of academic interest really, as there's nothing you can do to fix it, other than erase the EPROM and start again. Perhaps it would be a good idea to have a second, blank, EPROM on hand in case you boo-boo with the first.

What could have gone wrong? Maybe you forgot to reset the EPROM address counter. Maybe you forgot to switch the read/program switch correctly. Maybe it's just not your day for programming EPROMs. In that case relax, and go get a haircut!

Undoubtedly there will be those who want to assemble a program from the beginning of MicroBee memory (i.e: 0000). If you do this remember that the control program starts at 0E00 and hence only 3½K bytes may reside from 0000 to 0DFF. To avoid this restriction, assemble programs above the control program, i.e: starting at 1000. For example, if you have a 4K program temporarily residing at 1000 to 1FFF, then the steps to transfer it into EPROM are as follows (you must have a 2732 etc in the ETI-668!):

1) Reset the ETI-668 (press SW1), set SW2 to READ
2) Enter start address (= 1000)
3) Enter finish address (= 2000; note, *not* 1FFF)
4) Switch SW2 to PROGRAM
5) Type 'Control P' to program the EPROM

Then go through the verify routine. ▶

SIGNALS/VOLTAGES REQUIRED BY THE FIVE EPROM TYPES

24-pin package pin nos.		2716		2732		2532		2732A	2764	(28 pin)	28-pin package pin nos.
	read	prog.	read	prog.	read	prog.	read	prog.	read	prog.	
		⎍		⎍				⎍		⎍	
18	V_{1L}	V_{1H}	V_{1L}	V_{1L}	A_{11}	A_{11}	V_{1L}	V_{1L}	V_{1L}	V_{1L}	20
20	V_{1L}	V_{1H}	V_{1L}	+25 V	V_{1L}	V_{1L}	V_{1L}	+21 V	V_{1L}	V_{1L}	22
21	+5 V	+25 V	A_{11}	A_{11}	+5 V	+25 V	A_{11}	A_{11}	A_{11}	A_{11}	23
									+5 V	+21 V	1
									A_{12}	A_{12}	2
									+5 V	+5 V	28
									V_{1H}	V_{1L}	27

According to the data sheets, no two of the five EPROM types that can be programmed by the ETI-668 may be programmed with the same pin connections. Thus, the 6-pin 'personality' socket is used to customise the programmer for the EPROM in use. The above table shows the signals/voltages required for the five different EPROM types that can be programmed by the ETI-668.

```
ADDR   CODE     LINE   LABEL  MNEM    OPERAND

                00100 ;ETI668 / MICROBEE EPROM PROGRAMMER
                00110 ;        Tom Moffat, 19/12/82
                00120
0400            00130          DEFR    16
0E00            00140          ORG     0E00
                00150
0E00 010004     00160          LD      BC,400  ;CLEAR THE SCREEN
0E03 2100F0     00170 START    LD      HL,0F000
0E06 3620       00180 CLR      LD      (HL),20
0E08 23         00190          INC     HL
0E09 0B         00200          DEC     BC
0E0A 78         00210          LD      A,B
0E0B B1         00220          OR      C
0E0C 20F8       00230          JR      NZ,CLR
                00240
                00250 ;Enter start and finish addresses.
                00260
0E0E 21240F     00270          LD      HL,MSG  ;POINT TO MESSAGES
0E11 018DF0     00280          LD      BC,0F08DH
0E14 CD1B0F     00290          CALL    MESS    ;SHOW TITLE
0E17 0115F1     00300          LD      BC,0F115
0E1A CD1B0F     00310          CALL    MESS    ;SHOW START ADDRESS
0E1D CDEE0E     00320          CALL    ADDR
0E20 D5         00330          PUSH    DE
0E21 0195F1     00340          LD      BC,0F195
0E24 CD1B0F     00350          CALL    MESS    ;SHOW FINISH ADDRESS
0E27 CDEE0E     00360          CALL    ADDR
0E2A 0115F2     00370          LD      BC,0F215
0E2D CD1B0F     00380          CALL    MESS    ;SHOW COMMAND
                00390
                00400 ;Enter command, then jump.
                00410
0E30 CD0680     00420 COM      CALL    8006    ;GET KEY
0E33 FE10       00430          CP      10
0E35 2819       00440          JR      Z,PROG
0E37 FE12       00450          CP      12
0E39 2826       00460          JR      Z,READ
0E3B FE13       00470          CP      13
0E3D 2831       00480          JR      Z,STEP
0E3F FE14       00490          CP      14
0E41 283B       00500          JR      Z,TEST
0E43 FE16       00510          CP      16
0E45 2849       00520          JR      Z,VRFY
0E47 FE03       00530          CP      3
0E49 20E5       00540          JR      NZ,COM
0E4B 011F02     00550          LD      BC,21FH
0E4E 18B3       00560          JR      START
                00570
                00580 ;PROGram from memory to EPROM.
                00590
0E50 21800F     00600 PROG     LD      HL,PROGM
0E53 3E0F       00610          LD      A,0FH   ;SET PIO FOR OUTPUT
0E55 CD190F     00620          CALL    INIT+2
0E58 E1         00630          POP     HL
0E59 7E         00640 PROG1    LD      A,(HL)  ;GET BYTE FROM MEMORY
0E5A D300       00650          OUT     (0),A   ;SEND IT TO EPROM
0E5C CDB10E     00660          CALL    SHODL   ;SHOW ADDR THEN DELAY
0E5F 18F8       00670          JR      PROG1
                00680
                00690 ;READ from EPROM to memory.
                00700
0E61 21860F     00710 READ     LD      HL,READM
0E64 CD170F     00720          CALL    INIT
0E67 E1         00730          POP     HL
0E68 DB00       00740 READ1    IN      A,(0)   ;BRING IN A BYTE
0E6A 77         00750          LD      (HL),A  ;STORE IT IN MEMORY
0E6B CDB10E     00760          CALL    SHODL
0E6E 18F8       00770          JR      READ1
                00780
                00790 ;STEP to new address.
                00800
0E70 218C0F     00810 STEP     LD      HL,STEPM
0E73 CD170F     00820          CALL    INIT
0E76 E1         00830          POP     HL
0E77 DB00       00840 STEP1    IN      A,(0)   ;FIRE TRIGGER PULSE ONLY
0E79 CDB10E     00850          CALL    SHODL
0E7C 18F9       00860          JR      STEP1
                00870
                00880 ;TEST for complete EPROM erasure.
                00890
0E7E 21920F     00900 TEST     LD      HL,TESTM
0E81 CD170F     00910          CALL    INIT
0E84 E1         00920          POP     HL
0E85 DB00       00930 TEST1    IN      A,(0)   ;GET BYTE FROM EPROM
0E87 FEFF       00940          CP      0FFH    ;IS IT ERASED?
0E89 2017       00950          JR      NZ,ERROR
0E8B CDB10E     00960          CALL    SHODL
0E8E 18F5       00970          JR      TEST1
                00980
                00990 ;VERIFY memory and EPROM are the same.
                01000
0E90 21980F     01010 VRFY     LD      HL,VRFYM
0E93 CD170F     01020          CALL    INIT
0E96 E1         01030          POP     HL
0E97 DB00       01040 VRFY1    IN      A,(0)   ;GET BYTE FROM EPROM
0E99 4E         01050          LD      C,(HL)  ;GET BYTE FROM MEMORY
0E9A B9         01060          CP      C       ;ARE THEY THE SAME?
0E9B 2005       01070          JR      NZ,ERROR
0E9D CDB10E     01080          CALL    SHODL
0EA0 18F5       01090          JR      VRFY1
                01100
                01110 ;Show an ERROR message.
                01120
0EA2 21730F     01130 ERROR    LD      HL,ERRM
0EA5 0199F2     01140          LD      BC,0F299
0EA8 CD1B0F     01150          CALL    MESS
0EAB 0607       01160          LD      B,7
0EAD CD0C80     01170          CALL    800CH   ;BEEP!
0EB0 76         01180          HALT            ;SWEAR AND HIT RESET.
                01190
                01200 ;Show HL and do time delay.
                01210
0EB1 0124F2     01220 SHODL    LD      BC,0F224;SCREEN LOCATION
0EB4 3EA0       01230          LD      A,0A0
0EB6 02         01240          LD      (BC),A  ;SHOW A WHITE SPACE
0EB7 03         01250          INC     BC
0EB8 23         01260          INC     HL      ;TO MATCH EPROM COUNTER
0EB9 7C         01270          LD      A,H
0EBA CDD80E     01280          CALL    SHOW    ;SHOW H REG
0EBD 7D         01290          LD      A,L
0EBE CDD80E     01300          CALL    SHOW    ;SHOW L REG
0EC1 3EA0       01310          LD      A,0A0
0EC3 02         01320          LD      (BC),A  ;SHOW A WHITE SPACE
0EC4 010010     01330          LD      BC,1000 ;55 MS TIME DELAY
0EC7 0B         01340          DEC     BC
0EC8 78         01350          LD      A,B
0EC9 B1         01360          OR      C
0ECA 20FB       01370          JR      NZ,$-3
0ECC E5         01380          PUSH    HL
0ECD ED52       01390          SBC     HL,DE
0ECF E1         01400          POP     HL
0ED0 D8         01410          RET     C       ;FINISHED?
0ED1 011F02     01420          LD      BC,21FH ;FOR PARTIAL SCREEN CLEAR
0ED4 E1         01430          POP     HL      ;CLR RET OFF STACK
0ED5 C3030E     01440          JP      START   ;FINISHED.
                01450
                01460 ;Show "A" register as a hex value.
                01470
0ED8 F5         01480 SHOW     PUSH    AF
0ED9 0F         01490          RRCA
0EDA 0F         01500          RRCA
0EDB 0F         01510          RRCA
0EDC 0F         01520          RRCA
0EDD CDE10E     01530          CALL    $+4
0EE0 F1         01540          POP     AF
0EE1 E60F       01550          AND     0FH
0EE3 C6B0       01560          ADD     A,0B0
0EE5 FEBA       01570          CP      0BAH
0EE7 3802       01580          JR      C,$+4
0EE9 C607       01590          ADD     A,7
0EEB 02         01600          LD      (BC),A
0EEC 03         01610          INC     BC
0EED C9         01620          RET
                01630
                01640 ;Enter an address, show it, and put it in DE.
                01650
0EEE CDF20E     01660 ADDR     CALL    $+4
0EF1 53         01670          LD      D,E
0EF2 CD000F     01680          CALL    KEY
0EF5 07         01690          RLCA
0EF6 07         01700          RLCA
0EF7 07         01710          RLCA
0EF8 07         01720          RLCA
0EF9 5F         01730          LD      E,A
0EFA CD000F     01740          CALL    KEY
0EFD B3         01750          OR      E
0EFE 5F         01760          LD      E,A
0EFF C9         01770          RET
                01780
                01790 ;Get a Key, convert to HEX, and show it.
                01800
0F00 03         01810 KEY      INC     BC
0F01 CD0680     01820 KEY1     CALL    8006    ;KEY INPUT INTO A
0F04 02         01830          LD      (BC),A
0F05 D630       01840          SUB     30      ;CONV FROM ASCII TO HEX
0F07 38F8       01850          JR      C,KEY1  ;IF LESS THAN ZERO
0F09 FE0A       01860          CP      0AH
0F0B F8         01870          RET     M       ;IF BETWEEN 00-09
0F0C D607       01880          SUB     7
0F0E FE0A       01890          CP      0AH
0F10 38EF       01900          JR      C,KEY1  ;IF LESS THAN 0A
0F12 FE10       01910          CP      10
0F14 30EB       01920          JR      NC,KEY1 ;IF MORE THAN 0F
0F16 C9         01930          RET
                01940
                01950 ;Initialize PIO and/or show a message.
                01960
0F17 3E4F       01970 INIT     LD      A,4FH   ;SET PIO FOR INPUT
0F19 D301       01980          OUT     (1),A
0F1B 7E         01990 MESS     LD      A,(HL)
0F1C 23         02000          INC     HL
0F1D FE24       02010          CP      '$'     ;"$" = MSG TERMINATOR
0F1F C8         02020          RET     Z
0F20 02         02030          LD      (BC),A
0F21 03         02040          INC     BC
0F22 18F7       02050          JR      MESS
                02060
0F24    45 54 49 20 36 36 38 20 2D 20 4D 69             'ETI 668 / MICROBEE
0F30    63 72 6F 42 65 65 20 45 70 72 6F 6D 20 50 72 6F 'EPROM PROGRAMMER$'
0F40    67 72 61 6D 6D 65 72 24 53 74 61 72 74 20 41 64 'Start address? $'
0F50    64 72 65 73 73 3F 20 24 46 69 6E 69 73 68 20 41 'Finish address?$'
0F60    64 64 72 65 73 73 3F 24 43 6F 6D 6D 61 6E 64 3F 'Command?  $'
0F70    20 20 24 23 25 5C 26 40 20 45 52 52 4F 52 21 24 '#%\&@ ERROR!$'
                02130
                02140 ;Command labels, reverse video.
                02150
0F80 A0D0       02160 PROGM    DEFW    0D0A0   ; P
0F82 D2CF       02170          DEFW    0CFD2   ;RO
0F84 C724       02180          DEFW    24C7    ;G$
0F86 A0D2       02190 READM    DEFW    0D2A0   ; R
0F88 C5C1       02200          DEFW    0C1C5   ;EA
0F8A C424       02210          DEFW    24C4    ;D$
0F8C A0D3       02220 STEPM    DEFW    0D3A0   ; S
0F8E D4C5       02230          DEFW    0C5D4   ;TE
0F90 D024       02240          DEFW    24D0    ;P$
0F92 A0D4       02250 TESTM    DEFW    0D4A0   ; T
0F94 C5D3       02260          DEFW    0D3C5   ;ES
0F96 D424       02270          DEFW    24D4    ;T$
0F98 A0D6       02280 VRFYM    DEFW    0D6A0   ; V
0F9A D2C6       02290          DEFW    0C6D2   ;RF
0F9C D924       02300          DEFW    24D9    ;Y$
                02310
0000            02320          END
00000 Total errors

KEY1    0F01    KEY     0F00    SHOW    0ED8    ERRM    0F73
VRFY1   0E97    VRFYM   0F98    ERROR   0EA2    TEST1   0E85
TESTM   0F92    STEP1   0E77    STEPM   0F8C    READ1   0E68
READM   0F86    SHODL   0EB1    PROG1   0E59    INIT    0F17
PROGM   0F80    VRFY    0E90    TEST    0E7E    STEP    0E70
READ    0E61    PROG    0E50    COM     0E30    ADDR    0EEE
MESS    0F1B    MSG     0F24    CLR     0E06    START   0E03
```

0-40 V/5 A laboratory power supply Part 1.

Here's a laboratory standard power supply featuring truly regulated output from zero to 40 volts capable of delivering a massive 5 A across the whole voltage range, plus current limiting variable from zero to 5 A. Two meters monitor voltage and current and regulator dissipation is reduced by employing an automatic transformer switching circuit.

David Tilbrook

IN APRIL 1976 we published the ETI-131 General Purpose Power Supply. This project could be built in two versions — 0-20 V/2.5 A or 0-40 V/1.25 A. It featured variable current limiting and had pretty close to lab-standard specs. A great many have been built since then and are to be found in development laboratories, service workshops, technical college and university labs and hobbyist's workshops.

Since that time, electronic technology has made considerable strides and the sort of things now being investigated by hobbyists and in electronics labs of all descriptions range much wider than they did when the ETI-131 was in vogue. It came to our notice that a lab-standard supply having 'expanded' specifications was in demand so we set out to investigate what sort of project would best meet that demand.

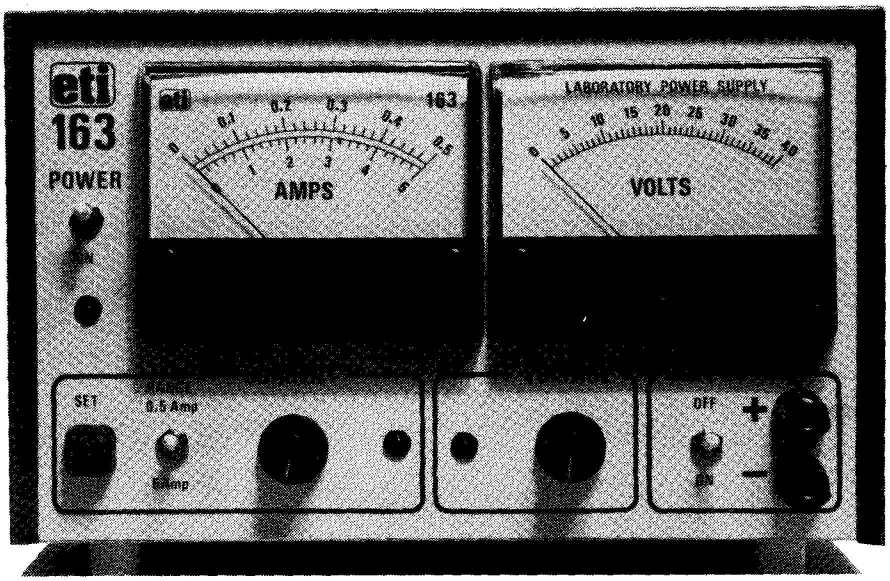
Following considerable discussion with both users and project suppliers, it was apparent that the most generally useful output voltage range would be about 0-40 V or 0-50 V and the required maximum current capability would be in the vicinity of 3-4 A or so. The next thing to do was to define 'lab-standard'.

Defining 'lab-standard'

An 'ideal' power source should provide the following: • a regulated voltage variable from zero to some chosen limit • no extraneous hum or noise on the output and none radiated from the supply • current-limit operation from zero to some chosen limit • simultaneous metering of current and voltage output • protection from short circuits on the output at any output setting.

In addition, handy 'operator features', such as indicators to show voltage and current mode operation, output and current-set switches, are desirable.

What sort of specifications would approach the 'ideal'? With sensitive high gain, dc control, audio or RF circuitry attached to the supply during circuit development or fault locating, you want to be sure that any problem experienced is not caused by some characteristic of the power supply. Hence, hum and noise are an important consideration. ▶



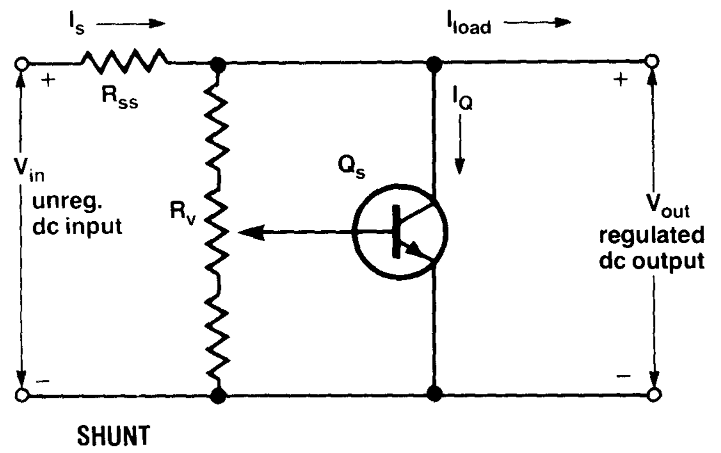
Power & Performance. The completed supply looks smart, performs well and is economical to build — at around $165-$175.

SPECIFICATIONS — ETI-163 LAB. SUPPLY

TABLE 1

Output voltage	0-40 V, variable
Output current	0-0.5 A, variable limiting 0-5 A, variable limiting
Output regulation	<50 mV at up to 2.5 A <100 mV up to 5 A
Ripple and noise	
voltage mode	<3 mV RMS
current mode	<10 mV RMS
Maximum output power	200 watts
Metering	
Voltage	0-40 V in 1 V divisions
Current	0-0.5 A in 20 mA divisions 0-5 A in 200 mA divisions

- **LED to indicate voltage mode operation**
- **LED to indicate current mode (limiting) operation**
- **Current-set switch provided for setting current limit value**
- **Output switch provided to isolate supply output**
- **Output terminals isolated from chassis**
- **Full output current available right up to 40 V**



The shunt regulator. Fundamental circuit of a shunt regulator. As the load current (I_{load}) increases, the output voltage (V_{out}) tends to fall, reducing base current to Q_s. This, in turn, reduces the collector current (I_Q) of the shunt regulator, Q_s. The voltage drop across R_{ss} then decreases, maintaining the output voltage. As load current decreases, the opposite happens.

If the input voltage (V_{in}) increases, V_{out} tends to rise, increasing the base current to Q_s. This increases I_Q and the voltage drop across R_{ss} increases, maintaining the output voltage. If V_{in} decreases, the opposite happens.

Varying the wiper of R_v varies the collector current of Q_s, thus varying the voltage dropped across R_{ss}, setting the output voltage. Resistor, R_{ss} dissipates considerable power and Q_s dissipates the maximum output power under no load.

A figure under 10 mV is a desirable goal, preferably less than 5 mV. Performance in the current-limit mode should be similar, but is not as critical a parameter.

As supply voltage variations can adversely affect some circuits, regulation of the output voltage over the whole variation range is paramount. It should remain virtually constant despite relatively large mains input voltage excursions and despite large variations in current drawn (up to the maximum). Regulation can be expressed as a percentage (with respect to full output) or as a voltage variation. The latter is preferred as it shows performance over the whole output variation range.

A regulation figure of 0.1% (100 mV in 100 V) is common for low current output supplies (up to 1 A), but 0.5% is more usual for high current supplies. That would be 250 mV for a 50 V supply.

Regulator techniques

There are a number of basic techniques used to provide a regulated supply voltage. Choice depends on the application. The respective methods and their characteristics may be summarised as follows:

- **The shunt regulator.** This design is suitable mainly for low-power supplies — 15 to 20 watts. It has good regulation and is inherently short circuit proof. However, it dissipates the full amount of power it is capable of handling under no-load conditions.

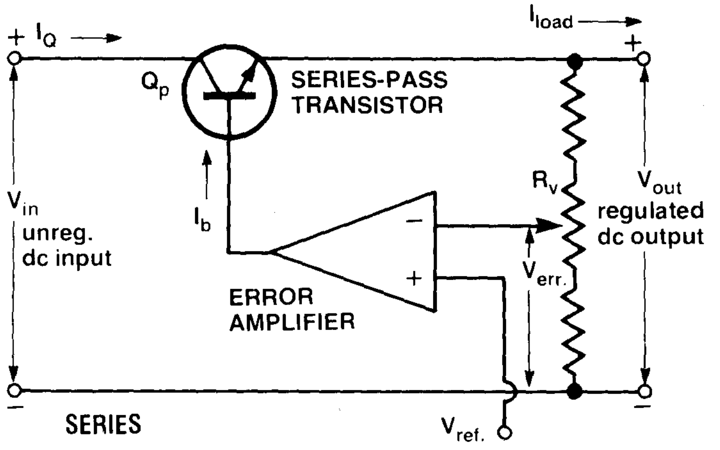
Current-limit operation is not so easy to incorporate, but cost is low.

- **The series regulator.** Probably the most widely used technique. It is suitable for power supplies capable of delivering up to 200 watts.

Regulation, hum and noise performance is good, it's easy to arrange current-limit operation and cost is relatively low.

- **SCR regulator.** This technique is mainly suited for medium to very high power applications. The regulator has low dissipation and good regulation, but output noise and ripple are worse than for the series regulator and radiated switching 'hash' requires extensive shielding.
- **SCR pre-regulator and series regulator.** This combines the best features of the previous two and is best suited to medium to high power applications (say to several hundred watts).

An SCR pre-regulator provides a roughly regulated supply about five volts above the required output voltage, followed by a conventional series regulator. This keeps dissipation in the series regulator low. Cost is relatively high.



The series regulator. Fundamental circuit of a series regulator. As the load current (I_{load}) increases, the output voltage (V_{out}) tends to fall. This causes $V_{err.}$ to fall (the 'error voltage'). The error amplifier is operated as an inverting amplifier and thus, as $V_{err.}$ falls, the base current (I_b) to the series-pass transistor (Q_p) will rise. This causes the collector current (I_Q) of Q_p to rise, maintaining the output voltage. If I_{load} decreases, the opposite occurs.

If the input voltage (V_{in}) rises, the output will tend to rise, as will $V_{err.}$. This will produce a decrease in base current to Q_p, reducing I_Q, thus maintaining the output voltage. If V_{in} falls, the opposite will occur.

Varying the wiper of R_v varies $V_{err.}$, setting the output voltage.

- **Switchmode regulator.** This technique is also used in medium to very high power applications. A series switching element stores energy in an inductor or capacitor, the on-time of the switching element being controlled to provide the required regulated output.

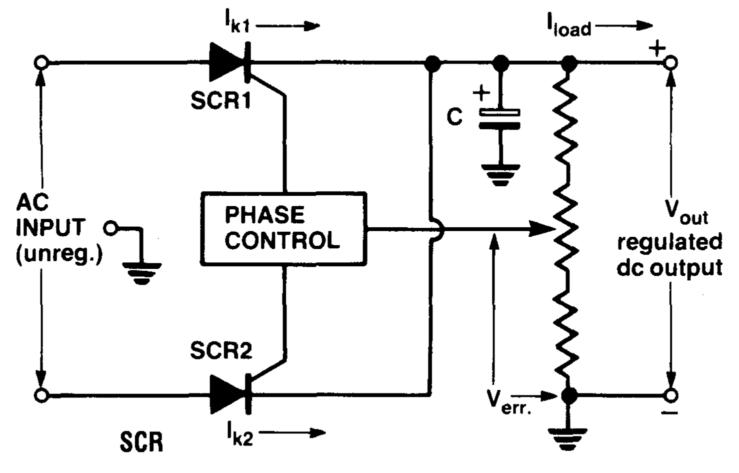
This technique keeps regulator dissipation low and regulation performance is good. With modern ICs purpose-built for the application, cost is about the same as a series regulator. However, noise and ripple on the output can be difficult to suppress and considerable wideband RF energy is radiated by the circuitry, necessitating careful and extensive shielding.

Design features of this supply

I settled on an output voltage range of 0-40 V as this seemed to cover the great majority of supply requirements for circuit testing, development and fault locating. A maximum output current of 5 A was settled on for similar reasons. This results in an output rating of 200 watts, hence choice of an appropriate regulator technique was of paramount importance.

Two techniques were obvious contenders — series regulator and switchmode regulator. Previous experience with switchmode regulators made me wary that I could use one in a 'lab-standard' supply. The ETI-142 0-30 V/15 A supply (Feb. '79) employed a switchmode pre-regulator and a series regulator. Despite elaborate precautions, noise from the switchmode pre-regulator made it impossible to use this supply in the vicinity of, let alone connected to, sensitive circuitry. Pity, but a fact of life.

The inherent attractiveness of high efficiency — low dissipation is generally outweighed in this application. The necessity of elaborate screening and filtering brings problems of its own for constructors and increases costs.



The SCR regulator. Fundamental circuit of an SCR regulator. As the load current (I_{load}) increases, the output voltage (V_{out}) tends to decrease causing the 'error voltage' ($V_{err.}$) to drop. The phase control circuit then advances the triggering of the SCRs so that I_{k1} and I_{k2} and the average rectified voltage increases, maintaining the output voltage. If load current decreases, the opposite occurs.

If the ac input voltage rises, V_{out} tends to rise, causing $V_{err.}$ to rise also. The phase control circuit then retards the triggering of the SCRs, reducing the average rectified voltage, and maintaining V_{out}. The opposite happens if the ac input falls.

Varying the potentiometer varies $V_{err.}$, setting the output voltage.

I looked at the series regulator — and how to reduce the dissipation. For a 40 V output, dc input to the regulator would have to be around 50 V. At 5 A output into a short circuit, worst case dissipation would be around 250 watts! That requires *big* transistors and *lots* of heatsink.

As pre-regulators increased the cost and the noise problems, I had to find another way to reduce regulator dissipation and I hit on the idea of switching the transformer secondary.

Using several cheap ICs as comparators and a couple of relays, I could switch the rectifier across different transformer taps as the regulator output voltage was varied.

However, this technique had the drawback that a 'special' transformer would be required. If I could choose the output taps so that they were at generally 'useful' voltages, the transformer stood a good chance of becoming a 'stock' item. With this in mind, I chose the secondary taps to be 12 V, 24 V and 36 V.

The prototype transformer was wound up for us by Permatran of Melbourne. It is rated at 250 VA.

Astute readers will notice that basically, only two output taps are really required as the 12 V output could be selected by switching between the 24 and 36 volt terminations. However, using relay switching, it is possible under some circumstances to short part of the secondary with consequent disastrous results. The 'switching' tree employed avoids this possibility.

A separate low voltage and current dc supply is necessary to power the op-amps in the regulator and to provide a 5 V reference. In the prototype, I used a small 12 V/150 mA transformer — a stock item from most electronics suppliers — but a 15 V/200 mA winding may be available on the transformers obtained by suppliers of this project.

Worst case regulator dissipation for this supply is around 120 watts, a much more manageable figure than 250 watts. It occurs when the output current is 5 A at a voltage setting near 25 volts. At maximum dissipation, the heatsinks stabilise at a temperature of around 65°C.

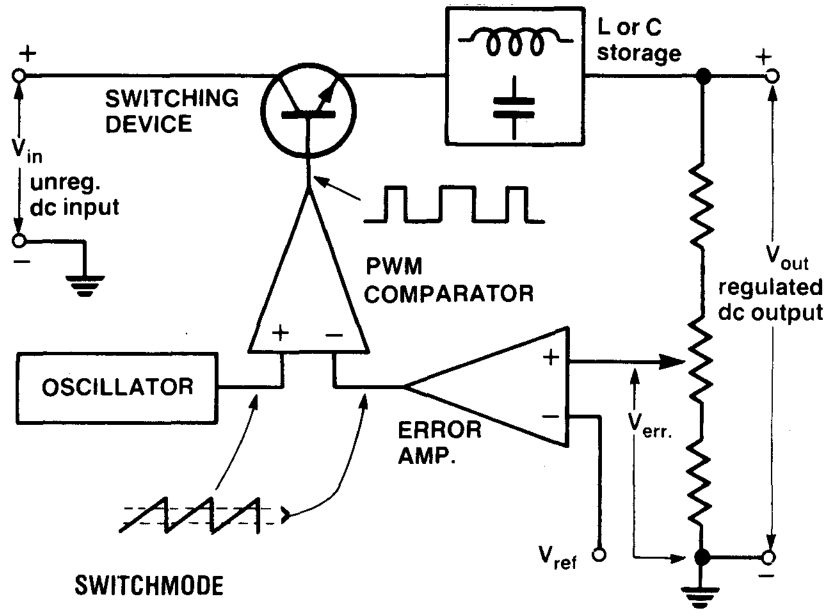
The regulator circuit is similar to the ETI-131 and employs two CA3130s for the voltage-mode and current-mode error amplifiers. A pair of MJ15003 high power NPN transistors connected in parallel are used for the series-pass element.

Another pair of CA3130s are used as comparators for the transformer secondary relay switching circuitry. These were chosen because their output can go right down to 0 V, ensuring the relay driver transistors turn off. The transformer taps are switched as the output voltage passes through about 12 V and about 25 V (these are adjustable over a few volts range). About a volt of hysteresis is added to the switching points so that the relays won't chatter when the output control is set on the switching point.

Separate meters are provided for indicating output voltage and current. There are two current-limit ranges — zero to 0.5 A and zero to 5 A. The point at which the supply switches from constant-voltage to current-limited (constant-current) output is fully variable across the two ranges.

A current-set pushbutton, which shorts the output terminals, is provided on the front panel and two LEDs indicate in which mode the supply is operating. A switch in series with the output allows you to isolate the supply from the load, without having to disconnect the supply or turn it off if you want the supply removed.

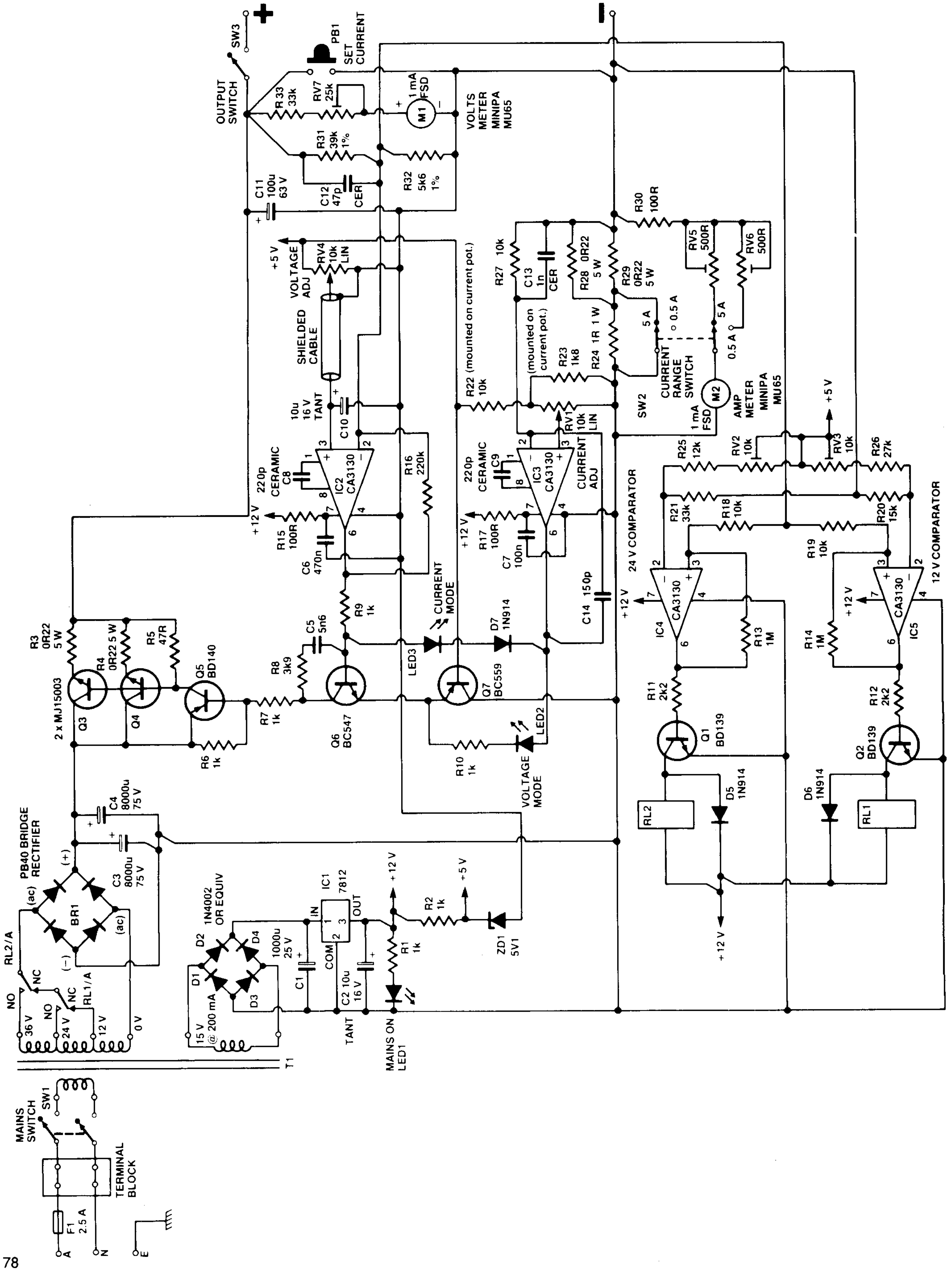
Performance turns out to be generally better than what was discussed as desirable for a lab-standard supply. See Table 1 for a complete run-down. ▶



The switchmode regulator. Fundamental circuit of a switchmode regulator. The output of a sawtooth oscillator and the output level of the 'error amplifier' are compared by the 'pwm comparator' which drives a switching device. The switching device turns on and off, storing energy from the unregulated input in a capacitor or inductor.

As the load current increases, the output voltage (V_{out}) will tend to fall as will the error voltage ($V_{err.}$). The output of the pwm comparator will turn on for a longer period for each cycle of the sawtooth. The switching device then conducts for a longer period, storing more energy in the L or C, maintaining the output voltage. As the output current decreases, the opposite occurs.

As the switching device is either hard on or fully off, it dissipates little power. Varying the potentiometer varies $V_{err.}$, setting the output voltage.


OUTPUT SWITCH
SW3
+
−
PB1 SET CURRENT
R33 33k
RV7 25k
1 mA FSD
M1
VOLTS METER MINIPA MU65
R31 39k 1%
C12 47p CER
R32 5k6 1%
C11 100u 63 V
+5 V
VOLTAGE ADJ
RV4 10k LIN
SHIELDED CABLE
10u 16 V TANT
C10
220p CERAMIC C8
IC2 CA3130
R16 220k
+12 V
R15 100R
C6 470n
R22 (mounted on current pot.) 10k
R27 10k
C13 1n CER
R28 0R22 5 W
R29 0R22 5 W
R30 100R
RV5 500R
RV6 500R
(mounted on current pot.)
R23 1k8
R24 1R 1 W
5 A
0.5 A
CURRENT RANGE SWITCH
SW2
M2
1 mA FSD
AMP METER MINIPA MU65
RV1 10k LIN
CURRENT ADJ
220p CERAMIC C9
IC3 CA3130
R17 100R
C7 100n
C14 150p
24 V COMPARATOR
R25 12k
RV2 10k
RV3 10k
R26 27k
R21 33k
R18 10k
R20 15k
R19 10k
12 V COMPARATOR
IC4 CA3130
IC5 CA3130
R13 1M
R14 1M
R11 2k2
R12 2k2
Q1 BD139
Q2 BD139
D5 1N914
D6 1N914
RL2
RL1
+12 V
R3 0R22 5 W
R4 0R22 5 W
R5 47R
Q5 BD140
Q3
Q4
2 x MJ15003
R6 1k
R7 1k
R8 3k9
C5 5n6
R9 1k
Q6 BC547
CURRENT MODE
LED3
D7 1N914
Q7 BC559
R10 1k
LED2
VOLTAGE MODE
C4 8000u 75 V
C3 8000u 75 V
PB40 BRIDGE RECTIFIER
BR1
(ac)
(+)
(−)
RL2/A
RL1/A
NO
NC
36 V
24 V
12 V
0 V
D1
D2
D3
D4
1N4002 OR EQUIV
15 V @ 200 mA
C1 1000u 25 V
IC1 7812
IN
OUT
COM
C2 10u 16 V TANT
R1 1k
MAINS ON LED1
R2 1k
ZD1 5V1
T1
MAINS SWITCH SW1
TERMINAL BLOCK
F1 2.5 A
A
N
E

HOW IT WORKS — ETI-163

The power supply employs a series regulator circuit with current limiting operation added. The 36 V secondary of the power transformer has taps which are switched in automatically by relays as the output voltage is adjusted so that power dissipation in the series-pass transistors is minimised.

An auxilliary 15 V secondary (or an auxilliary transformer) provides a supply for the reference voltage, the relays, relay drive circuitry and voltage and current feedback op-amps (IC2 and IC3).

The main power transformer (T1) secondary of 36 volts is rated to deliver 5 A and is tapped at 12 and 24 volts. The appropriate tapping is selected by the contacts of relays RL1 and RL2.

These relays are controlled by Q1 and Q2, which are driven by a pair of comparators formed by IC4 and IC5 and associated resistors — R13, 14, 18 and 19. These resistors give the comparators some hysteresis which ensures that the relays do not chatter when the output voltage is set exactly equal to one of the trip voltages.

Resistors R21, 25, 20 and 26 and the two preset pots RV2 and RV3 form adjustable potential dividers, driven from the +5 V reference line. These potential dividers set the trip voltages for the two comparators. The presets allow the actual trip voltage to be adjusted over a small range.

Relay RL1 will trip when the voltage is around 12 V, while RL2 will trip when it is around 25 V. In this way the series-pass transistors, Q3 and Q4, are supplied with enough voltage to ensure good regulation but not excess voltage which would cause unneccessary power dissipation.

The main voltage regulator error amplifier is formed by IC2, a CA3130 FET-input op-amp. This compares the voltage on its non-inverting input (pin 3) with that on its inverting input (pin 2) which measures the output voltage via the potential divider formed by R31 and R32. The non-inverting input is connected to the wiper of RV4 which allows the reference voltage at this point to be varied from 0 to 5 V.

The output of IC2 is connected via resistor R9 to the base of Q6 which, in conjunction with Q5, provides the necessary current to drive the bases of the parallelled series-pass transistors, Q3 and Q4.

The RC network R8-C5 serves to provide negative feedback around Q6 and helps to ensure stability by reducing the gain of the circuit at high frequencies.

The tantalum capacitor C10 serves to filter the reference voltage. This is important since the error amplifier uses this voltage to establish the output voltage. Any ripple at the non-inverting input of IC2 will be amplified and appear at the output of the power supply. Capacitor C12 serves a similar purpose as C5 and controls the high frequency phase shift in the negative feedback loop to prevent oscillation. C8 provides compensation for IC2.

The current-limit error amplifier is formed by IC3 and associated components — C14, C9, R17 and C7. Resistor R17 and capacitor C7 simply form a low pass filter to ensure a reasonably clean supply to the op-amp. C9 compensates the op-amp and C14 provides feedback to decrease overall gain of the feedback loop at high frequencies, thereby ensuring stability when the supply is operating in the current-limit mode.

The non-inverting input to IC3 is connected to an adjustable voltage reference formed by RV1, R22 and R23. The inverting input is connected via R27 to the negative output terminal of the supply.

This op-amp is, in effect, measuring the voltage drop across the series resistance of R24, R28 and R29. This voltage is proportional to the current drawn from the supply. The amount of series resistance is switchable by the current range switch, SW2.

In the 5 A range, R24 is shorted by the switch providing a series resistance of 0.11 ohms. If for example, a 5 A current limit was desired, the current adjust pot. (RV1) would be adjusted, after depressing the current-set pushbutton (PB1) to give 5 A, and this would result in a 0.55 V reference voltage appearing at pin 3 of IC3. This op-amp then compares the reference voltage to the voltage developed across the series resistance.

IC3 will provide the appropriate output to bring its two inputs to the same voltage and, since 5 A will cause a 0.55 V drop across the series resistance, the load current will be limited to 5 A.

This assumes that the output voltage has been set high enough to force more than the desired current through the load. If this is not the case, it is impossible for the current error amp. to correct what it sees as a gross error in the current. The reference voltage at pin 3 of IC3 will be greater than the voltage at pin 2 so that the output of the op-amp is forced hard against its positive supply rail, i.e: around 12 V. This forward biases LED2, which indicates that the supply is in voltage mode. i.e: the output is controlled by the voltage pot.

If, however, the reference voltage has been set high enough so that the current flowing in the load approaches that set by the current limit potentiometer, then the current error amp takes over control of the feedback loop and maintains the output so that only the required current flows in the load.

The voltage error amp (IC2) is then incapable of correcting the output voltage and its output swings hard against its positive supply rail (12 V) in an attempt to do so. This forward biases LED3 which indicates that the supply is in current mode. i.e: the output is controlled by the current adjust pot., RV1.

The voltage meter, M1, is a straightforward milliameter arranged to measure voltage via series dropping resistors R33 and the preset RV7 — the latter being for the purpose of calibration.

The current meter, M2, is effectively a voltmeter, measuring the voltage developed across the series resistance in the negative output line of the supply. Independent presets RV5 and RV6 are provided to allow calibration of the two output current ranges.

A bridge rectifier (BR1) and two 8000u/75 V capacitors (C3, C4) provide the main supply for the regulator.

The voltage and current error amplifiers must be supplied with a 12 V rail obtained independently of the main tapped secondary winding of the transformer. This can be supplied from an auxilliary winding on the main transformer or from a second small transformer. It should be rated, at a minimum, to deliver 12 V at 150 mA, but a rating of 15 V at 200 mA provides a greater margin.

Diodes D1 to D4 rectify this supply, C1 providing smoothing. This is then regulated by IC1 to 12 V. A 5V1 zener diode connected across this supply provides the 5 V reference used by the reference inputs of the voltage and current error op-amps, IC2 and IC3.

The 'mains on' LED indicator, LED1, is powered from the +12 V rail by the series dropping resistor, R1. The output switch, SW1 permits 'turning off ' the supply output without turning off the mains. ●

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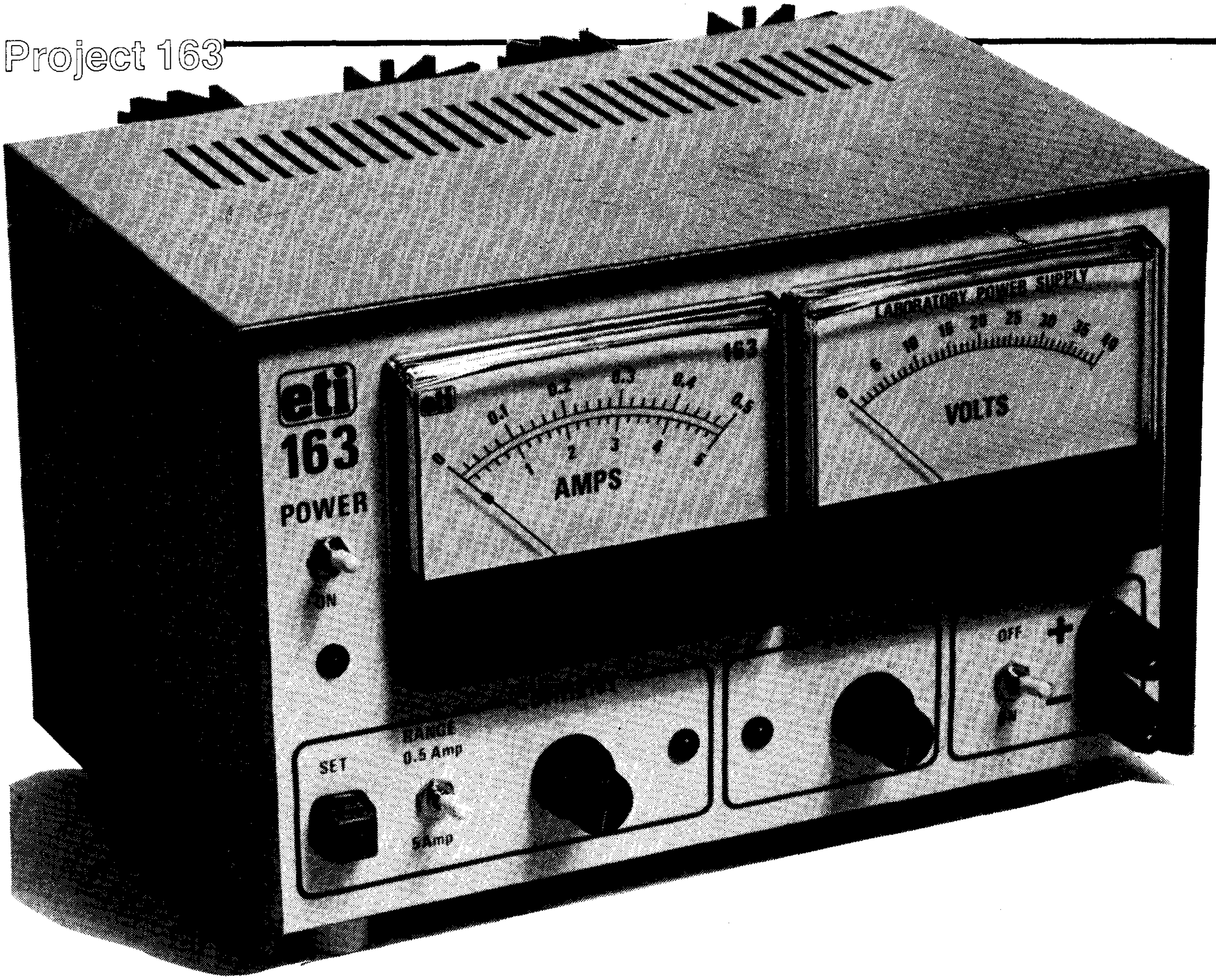


0-40 V/5 A laboratory power supply

Part 2.

Having introduced the project and the design technique chosen in Part 1, this part describes the construction and setting up.

David Tilbrook

Construction

This project is not recommended for beginners or inexperienced constructors. However, anyone with a modicum of electronics construction experience should be able to assemble this project with little difficulty.

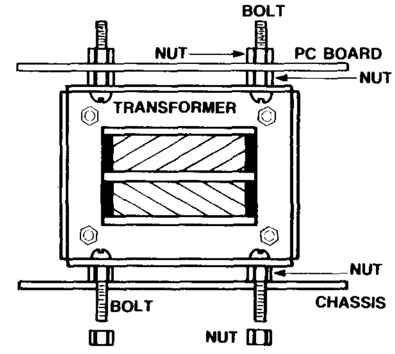
First off, no matter whether you've bought the components individually or purchased a kit, lay out all the parts and see that you have everything you need — including things like thermal compound, the right size nuts and bolts etc. Two basic grades of hookup wire are used to wire up the supply: ordinary 'light duty' (10 x 0.12 mm) hookup wire and 'heavy duty' (24 x 0.2 mm) or 'ultra heavy duty' (32 x 0.2 mm) wire. Those parts of the circuit carrying high currents are wired up with the heavy duty wire, as indicated in the wiring diagram.

The case we used is from K&W of Ballarat, Victoria, model C1066, supplied to us courtesy of Rod Irving Electronics. It is a popular and widely available case. Overall, it measures 255 x 165 x 155 mm and has a U-shaped aluminium chassis and hammertone blue steel lid with ventilation slots. It is supplied with four screw-on feet.

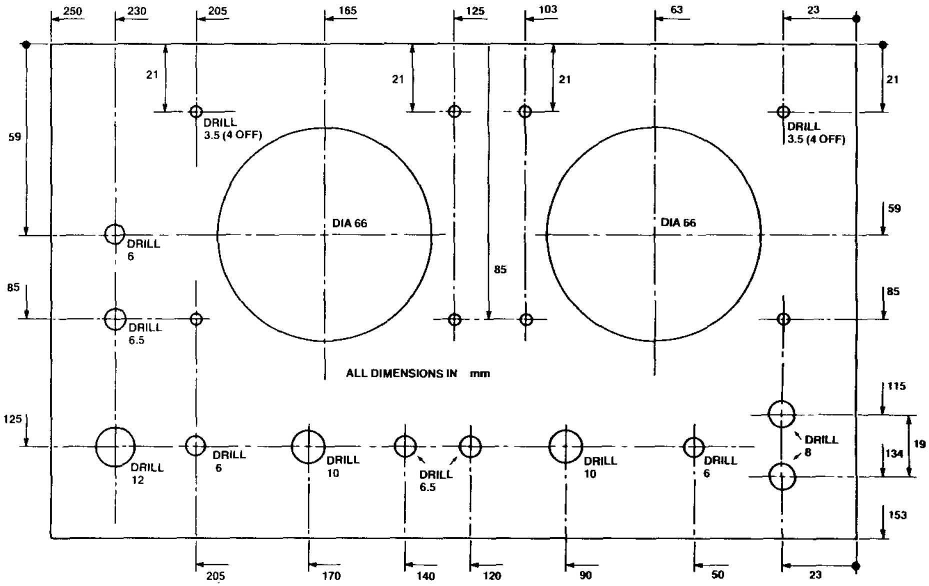
The chassis will need to be marked out and all holes drilled or cut out before any assembly can be commenced. Mark out the front panel according to the accompanying diagram. Centre punch all holes before drilling. Do a trial assembly of each component to see that they all fit and make any necessary adjustments.

No drilling diagrams have been given for the chassis bottom and rear panels as these will depend on the physical dimensions of the exact components used. Tackle the rear panel first. Place the two heatsinks side by side (see rear photograph), leaving room at the right for the mains fuse and power cord inlet. The two heatsinks we used were 150 mm lengths of black anodised radial fin type, manufactured and marketed by Rod Irving, No. HS3. There are similar types available. Any heatsink with suitable dimensions and rated dissipation of 1-1.3°C/watt will be perfectly adequate.

Holes will need to be drilled in the rear panel to accommodate the transistor mounting hardware, the transistor leads and bolts for securing the heatsinks. Having organised



Transformer and board mounting. How the power tranny, T1, and the pc board are mounted.



Get the drill? Drilling details for the front panel.

that, then locate the holes for the mains fuse holder and the power cord grommet — which should be a clamp type.

Mark out the case bottom next. Locate the mains transformer centrally between the sides and towards the rear, leaving no less than 15 mm clearance from the rear panel to the transformer bobbin. Four bolts are used to secure the transformer. Then locate and mark out the two filter capacitors, the bridge rectifier, the mains terminal block and earth bolt and the auxilliary 12 V (2851) transformer (if used). Make sure you don't foul the four case feet. Do a trial assembly to see it all fits correctly.

Remove burrs from all holes, then check that you've drilled all the required holes. Now stick masking tape across the rear (inside) of the front panel and spray paint the outside of it white. At the same time, remove the scale panels from the two meters, turn them over and spray paint them white, too. This ensures that the background for the Scotchcal labels is neutral as white Scotchcal is slightly translucent. Remove the masking tape from the chassis after the paint has dried.

Now the Scotchcal labels can be attached. Tackle the meter scales first. Peel off the backing along one edge for a little way then carefully align it on the edge of the scale panel and rub it down. Then peel off the backing further, rubbing down the Scotchcal carefully as you go. Take care not to get any, or many, bubbles under the Scotchcal label. If you do get some, they can be removed by rubbing them away towards the nearest edge. Work from the centre of the panel outwards.

Follow by applying the other meter scale Scotchcal and then the front panel. When the labels have been applied, cut out the holes using a modeller's scalpel or the like. Remember, a little patience prevents accidents. Re-assemble the meters.

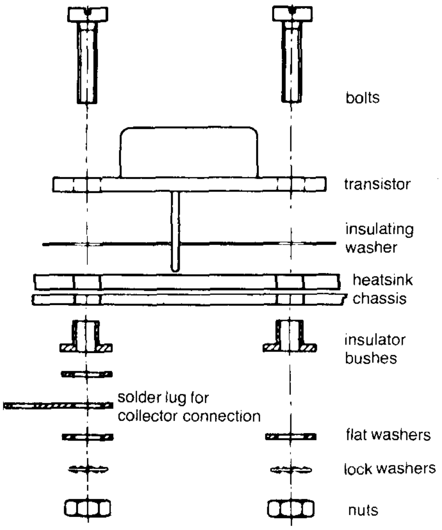
Now, you can mount all the front panel components — the meters, switches, output terminals, etc. Attach wires of appropriate length to them, as shown in the panel wiring diagram. Take care to use light duty and heavy duty hookup wire where indicated. Note that the lead from the voltage control potentiometer (RV4) to the pc board is a shielded cable. The shield braid is soldered only to the pot lug which connects to the 0 V output terminal and is left unconnected at the pc board.

Mount the rear panel components, but leave the mains cord off for the moment. Assemble the transistors to the heatsinks and chassis as indicated in the accompanying diagram. Attach wires to the transistors as per the wiring diagram.

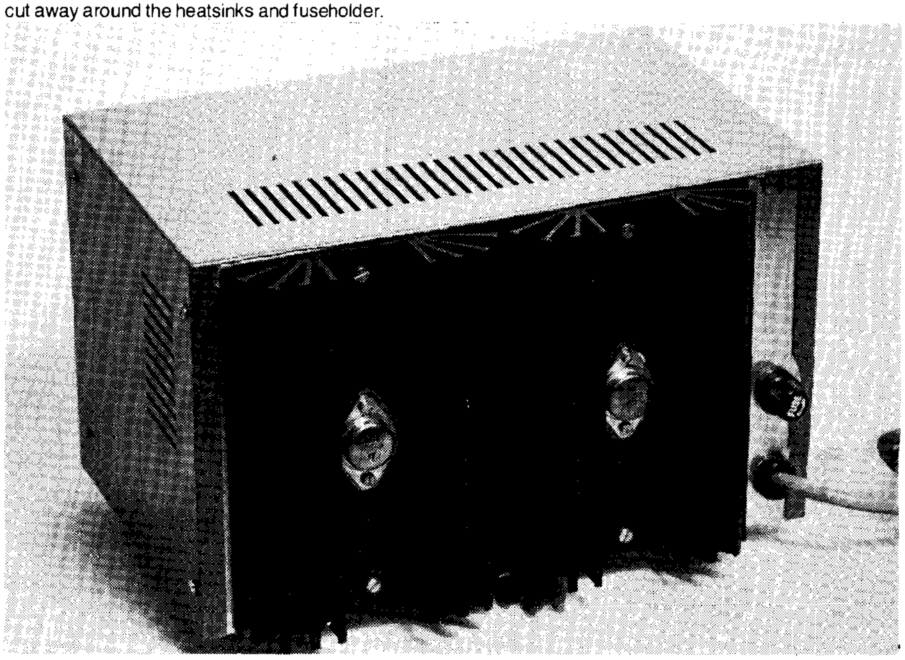
Mount the bridge rectifier and attach heavy duty leads of appropriate length to the lugs. Then mount the mains terminal block and the 2851 auxilliary transformer, if used. Wire the mains switch, mains fuse and mains terminal block. Sleeve the exposed fuse and switch connections. Mount the power transformer as per the diagram here, followed by the filter capacitors.

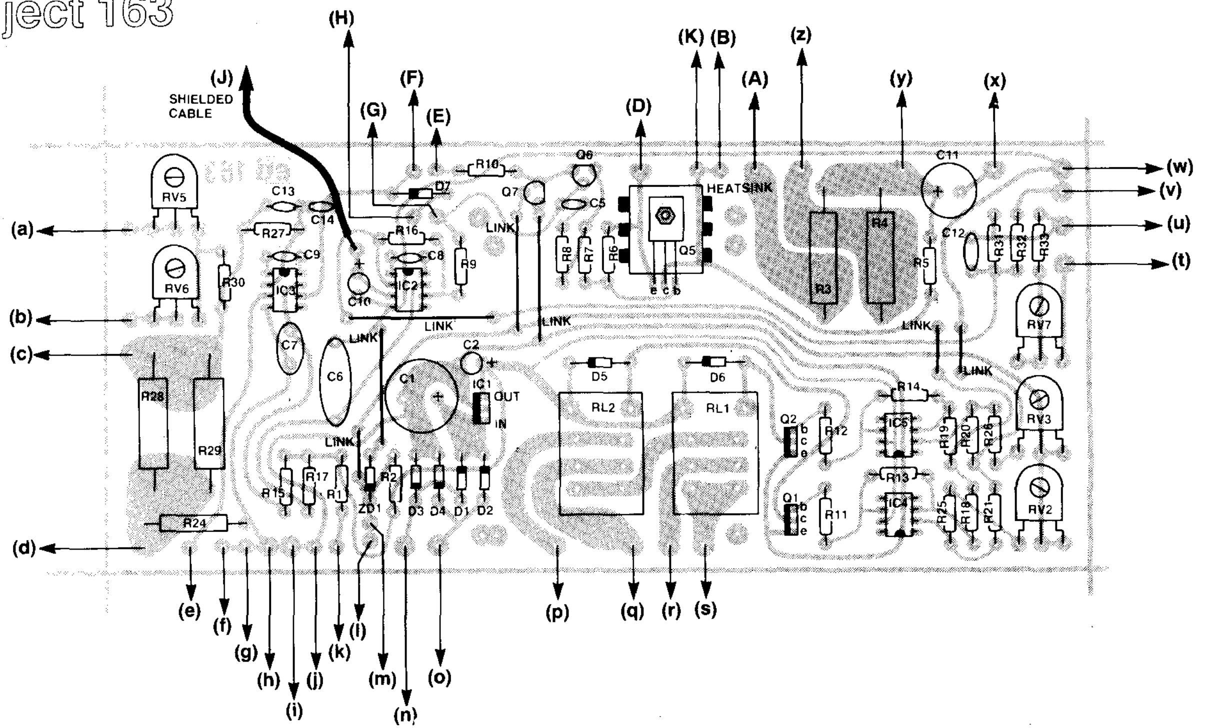
Assembly of the pc board can be tackled next. First, examine the tracks, looking for any breaks or hairline copper bridges between tracks. Check that all the holes are drilled and that they're of the correct size, particularly where the relays mount. ▶

Transistor mounting. How to mount the two power transistors, Q3 and Q4.



Rear view. Showing the components mounted on the rear panel. Note that the lip on the chassis lid needs to be cut away around the heatsinks and fuseholder.





If, or when, all's well with the board, commence assembly by soldering all the resistors and capacitors in place. Make sure you place the electrolytics and tantalums the right way round. The trimpots, note, are all laid flat on the board. Solder the pins in first, then carefully bend them so that the body lays flat.

The semiconductors may be soldered in place next. Check that each is correctly oriented before you solder it in place. If you wish, IC sockets may be used. Note that Q5, the BD140, requires a small heatsink. I used a Thermalloy No. 6073B, but any similar type that physically fits will do. Smear a little thermal compound on the metal face of the transistor before assembling it. No insulating washer is necessary.

The two relays can be mounted and soldered in place next, followed by all the pc stakes for terminating the leads to the components on the chassis.

The pc board bolts on top of the transformer. Note that provision has been made on the pc board for mounting holes to suit either the Permatran or the Ferguson transformer, whichever is used. It mounts on top of the transformer, as per previous diagram.

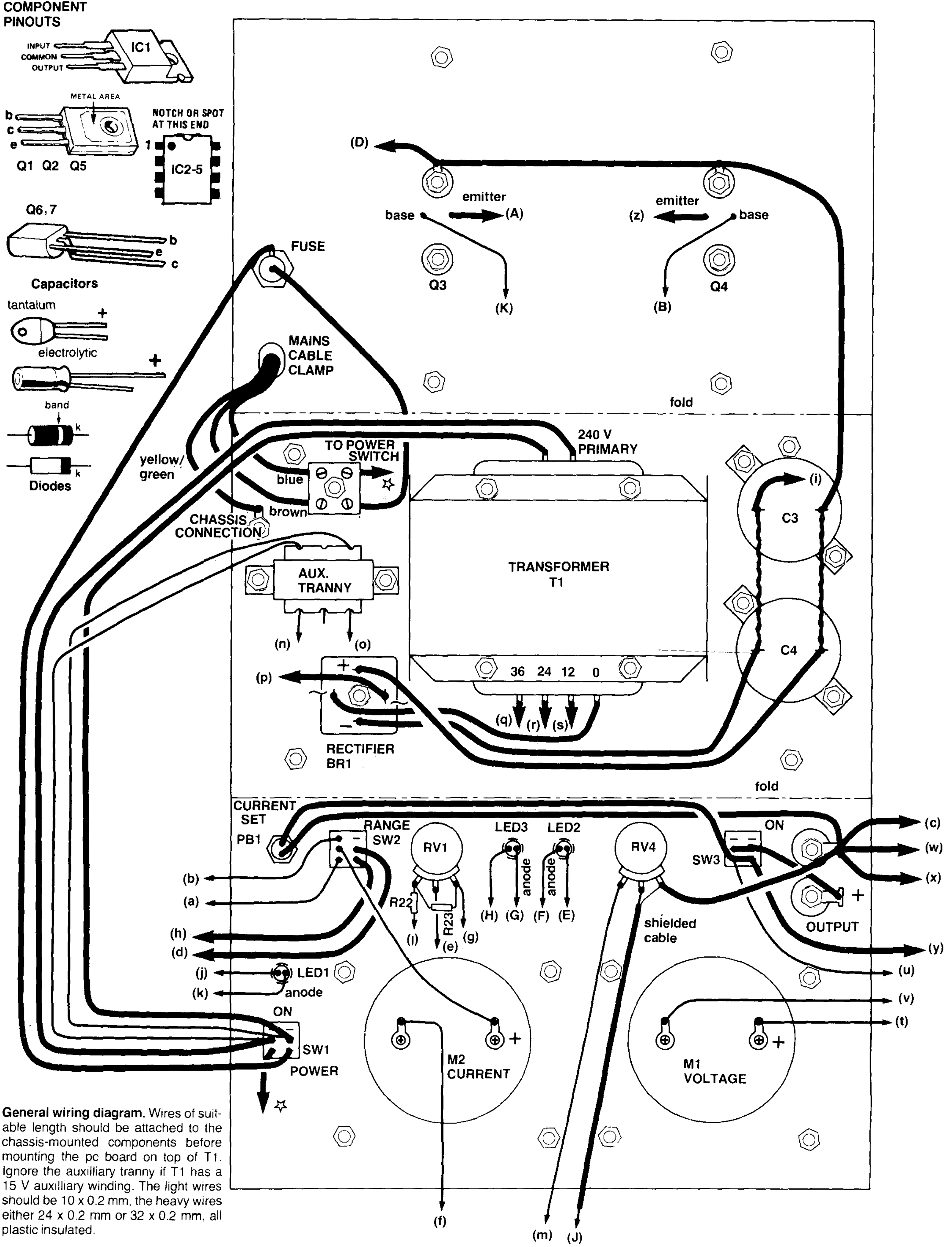
Referring to the wiring diagram, wire up the pc board. Route all the wires carefully. Check it thoroughly when you've finished. Last of all, wire in the mains cable. Make sure the earth (yellow/green) lead is the longest so that, should the cable be accidentally pulled out, the earth lead is the last to break. ▶

PARTS LIST — ETI-163

Resistors	all ¼ W, 5% unless noted
R1, 2, 6, 7, 9, 10	1k
R3, 4, 28, 29	0R22, 5 W
R5	47R
R8	3k9
R11, R12	2k2
R13, R14	1M
R15, R30	100R
R16	220k
R17	100R
R18, 19, 22, 27	10k
R20	15k
R21	33k
R23	1k8
R24	1R, 1 W
R25	12k
R26	27k
R31	39k, 1%
R32	5k6, 1%
R33	33k
RV1, RV4	10k/A panel mount pot.
RV2, RV3	10k/A min. vert. trimpots
RV5, RV6	500 R min. vert. trimpots
RV7	25k min. vert. trimpot
Capacitors	
C1	1000u/25 V single ended electro.
C2, C10	10u/16 V tantalum
C3, C4	8000u/75 V can electro.
C5	5n6 greencap
C6	470n greencap
C7	100n greencap
C8, C9	220p ceramic
C11	100u/63 V single ended electro.
C12	47p ceramic
C13	1n ceramic
C14	150p ceramic
Semiconductors	
BR1	PB40, MDA2504, MDA3504 etc bridge rectifier
D1, 2, 3, 4	1N4001 1N4002, etc
D5, 6, 7	1N914, 1N4148
Q1, Q2	BD139
Q3, Q4	MJ15003, MJ15024 etc
Q5	BD140
Q6	BC547, BC107 etc
Q7	BC559, BC159 etc
IC1	uA7812, LM7812 etc
IC2, 3, 4, 5	CA3130
LED1	TIL220R red LED
LED2	TIL220Y yellow LED
LED3	TIL220G green LED
ZD1	5V1
Miscellaneous	
F1	2.5 A or 3 A fuse, type 3AG, and bayonet holder (e.g: D.S.E. cat. S-4206 or similar).
M1, M2	Minipa MU65 1 mA meter movements, or similar.
PB1	SP momentary action pushbutton, 125 Vac/6 A contacts, D.S.E. No. S-1199 or similar.
RL1, RL2	DPCO heavy duty relays, 125 Vac/10 A contacts, 12 V coil (160 ohm), Fujitsu FRL-264D012/02CK (D.S.E. No. S-7140 or similar).
SW1	DPST miniature toggle switch, 240 Vac/1.5 A contacts or greater, D.S.E. No. S-1174 or S-1168, or similar.
SW2, SW3	DPDT miniature toggle switches, 240 Vac/5 A contacts, D.S.E. No. S-1168 or similar.
T1	transformer, 240 V primary, 250 VA rating, main secondary to deliver 36 V at 5 A or better, tapped at 12 and 24 V, with auxilliary secondary of 15 V at 200 mA (or additional 2851 12 V/150 mA transformer if 15 V secondary not available).

ETI-163 pc board; K&W case No. C1066; two heatsinks — Rod Irving No. HS3 150 mm long single-sided radial fin type black anodised, or similar (1°C/watt); one Thermalloy TO-220 heatsink 6073B or similar (for Q5); two heavy duty captive-head binding posts (one red, one black); one two-way terminal block; TO3 insulating components — two sets; one clamp grommet; mains cord and plug; Scotchcal labels for meter scales and front panel; short length of shielded cable; three LED mounts; hookup wire — light (10 x 0.12 mm) and heavy (24 x 0.2 mm or 32 x 0.2 mm); 6 BA and 4 BA bolts and nuts, solder lugs etc.

Price estimate $165 — $170



General wiring diagram. Wires of suitable length should be attached to the chassis-mounted components before mounting the pc board on top of T1. Ignore the auxilliary tranny if T1 has a 15 V auxilliary winding. The light wires should be 10 x 0.2 mm, the heavy wires either 24 x 0.2 mm or 32 x 0.2 mm, all plastic insulated.

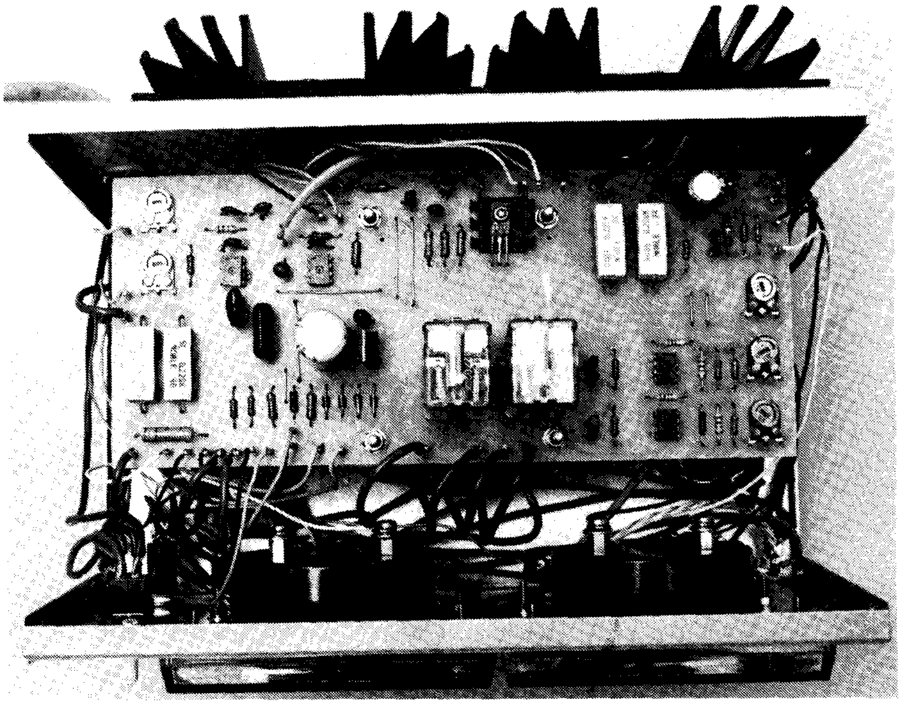
Now you're ready for the traditional 'smoke test'.

Test and set-up

Set all the trimpots to mid-position and the current and voltage controls a quarter-turn from minimum. Set the current range switch to 0.5 A and the output switch on. Plug the mains cord in and switch it all on.

The mains LED should come on, along with the voltage mode LED. The volts meter should read forwards, somewhere on the low end of the scale. If you don't get these indications, switch off and check for a wiring error (make sure you've a fuse in the fuseholder!).

Using a multimeter, check the voltage across the main filter capacitors (C3-C4). It should read around 17.5 V (with respect to the supply's negative output terminal — all readings are quoted with respect to this point). Check the voltage at pin 1 (in) of IC1 (i.e: at cathodes of D2-D4). This should be around 17.5 V if you're using the 12 V auxilliary transformer, or around 21 V if your main transformer has a 15 V auxilliary winding. Then check the output of IC1 (pin 3). It should be very close to 12 V. Check the voltage on the cathode of ZD1. It should be very close to 5.1 volts. No other voltages will tell you very much at this stage. If you don't get the correct readings switch off and check wiring and component placement. Correct any errors.



Top down view. Inside the lab. supply, showing board mounting and wiring.

If all's well, advance the voltage control until you hear RL1 'click' on. The voltage on the positive terminals of C3-C4 should then be around 36 V. Advance it further until RL2 clicks on and the voltage on the positives of C3-C4 should rise to about 54 V or so.

Now check the voltage across the output terminals. Vary the voltage control over the full range and ensure that you can vary it right from zero volts to a little over 40 V. We'll get around to calibrating the meter later.

The current-limit operation can now be checked. Set the output switch off. Connect your multimeter directly across the output terminals. Set it to the 5 A or 10 A range. Ensure the supply's current range switch is set to 0.5 A. Set the voltage control back to about a quarter-turn from minimum. Throw the output switch on. The voltage mode LED should go off and the current mode LED should go on. (This should also occur when the voltage control is set at minimum.) See that the multimeter reads a low current. If it doesn't, you've got the current range switch upside down.

Set the multimeter to a convenient scale (1 A or 2 A). Turn the current control around to maximum and see that the multimeter reads around 0.6-0.7 A. Now set the multimeter to the 10 A scale and the current range switch to 5 A. The multimeter should read between 6 A and 7 A.

If all's well, the two meters can now be calibrated.

First, the volts meter. With the multimeter still connected to the output terminals, set it to a convenient scale so that you can accurately read 20 V. Adjust the voltage control to obtain 20.0 V on the multimeter. Now adjust RV7 so that the volts meter on the project also reads precisely 20 V. Then set the voltage to read 5 V on the meter and check that the output's within ;0.25 V.

I have done this because many devices, TTL ICs and op-amps in particular, require accurate supply voltages and most are driven from supplies of less than 20 V. With TTL ICs a supply in excess of 5.5 V can destroy the device. Calibrating the meter at 20 V ensures that the meter accuracy at the low end is sufficient to obviate problems. If it's a volt or two out on the 20-40 V end of the scale, it doesn't matter so much.

To calibrate the current meter, first set the supply's output switch off. Set the current range switch to 0.5 A and set both the voltage and current controls about a quarter-turn off minimum.

Switch on the supply output and adjust the current control to obtain a reading of 500 mA on the multimeter. Then adjust RV6 so that the current meter reads full scale. Set the multimeter to the 5 A or 10 A scale and the current range switch to 5 A. Set the current control so that the multimeter reads 5.00 A and adjust RV5 so that the current meter reads full scale.

The current control has to be re-adjusted when switching from 0.5 A to 5 A as the current sensing resistor for the 5 A range is not exactly 0.1 ohms, being made up from two 0R22/5 W resistors in parallel which are the only ones generally available. Some tolerance in values will account for a difference in any case.

Now the relay 'trip' points can be set. Turn RV2 and RV3 fully anticlockwise. Set the output voltage to something less than 10 V. You can do this adjustment using either the project's volts meter or your multimeter connected across the output terminals.

Slowly advance the voltage control until the output is 12.5 V or thereabouts. Then rotate RV3 clockwise until RL1 just clicks in. This trimpot gives a trip point range of about 3 V from about 11 V to about 14 V. You may notice the output actually drop a few hundred millivolts when RL1 pulls in, but this is of no consequence.

Having done that, slowly advance the voltage control until the output voltage reaches about 25.5 V. Then rotate RV2 clockwise until RL2 clicks in. The output will drop a few hundred millivolts when you do this, but as before, it's unimportant. This trimpot has a trip point range of about 6 V, from roughly 24 V to about 30 V.

That's it! Now you can screw the lid down and put your ETI laboratory supply proudly on the workshop shelf.

Tips on using it

Always set up the power supply with the output switch *off*. Set the output voltage to what is required by the circuit you're working on. Then set the current limit range switch to the appropriate range, press the current set button and adjust the current control so that the current meter reads a little above what you expect the circuit to draw. Don't forget to allow for relay turn-on currents, lamps, indicators and etc in the circuit.

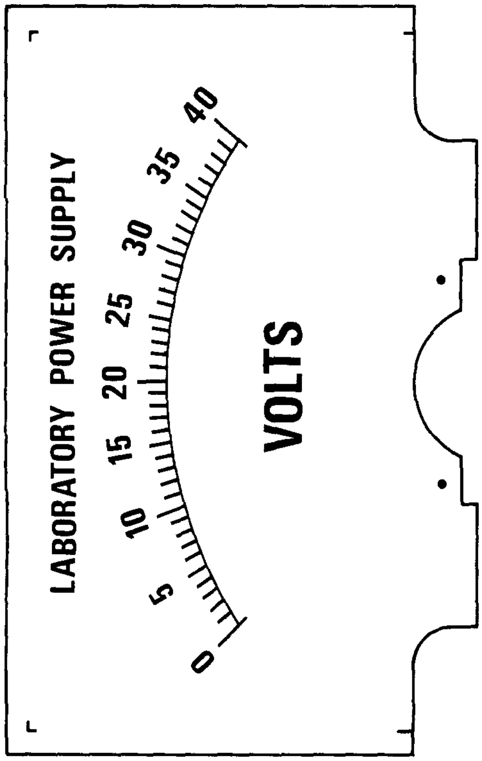
With straight CMOS circuits, even those with a dozen or more ICs, a current limit of 100-150 mA is a good safe limit.

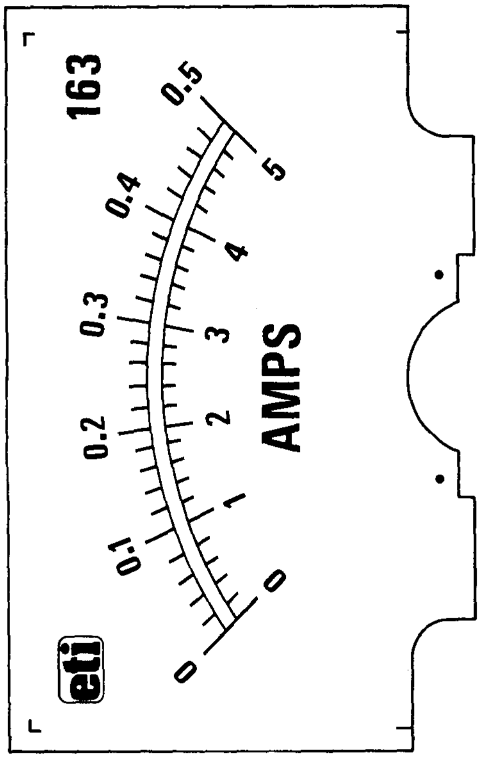
Beware of circuits which may draw peak currents several times the average current and set the current limit to take this into account (i.e: audio amplifiers, pulse circuits).

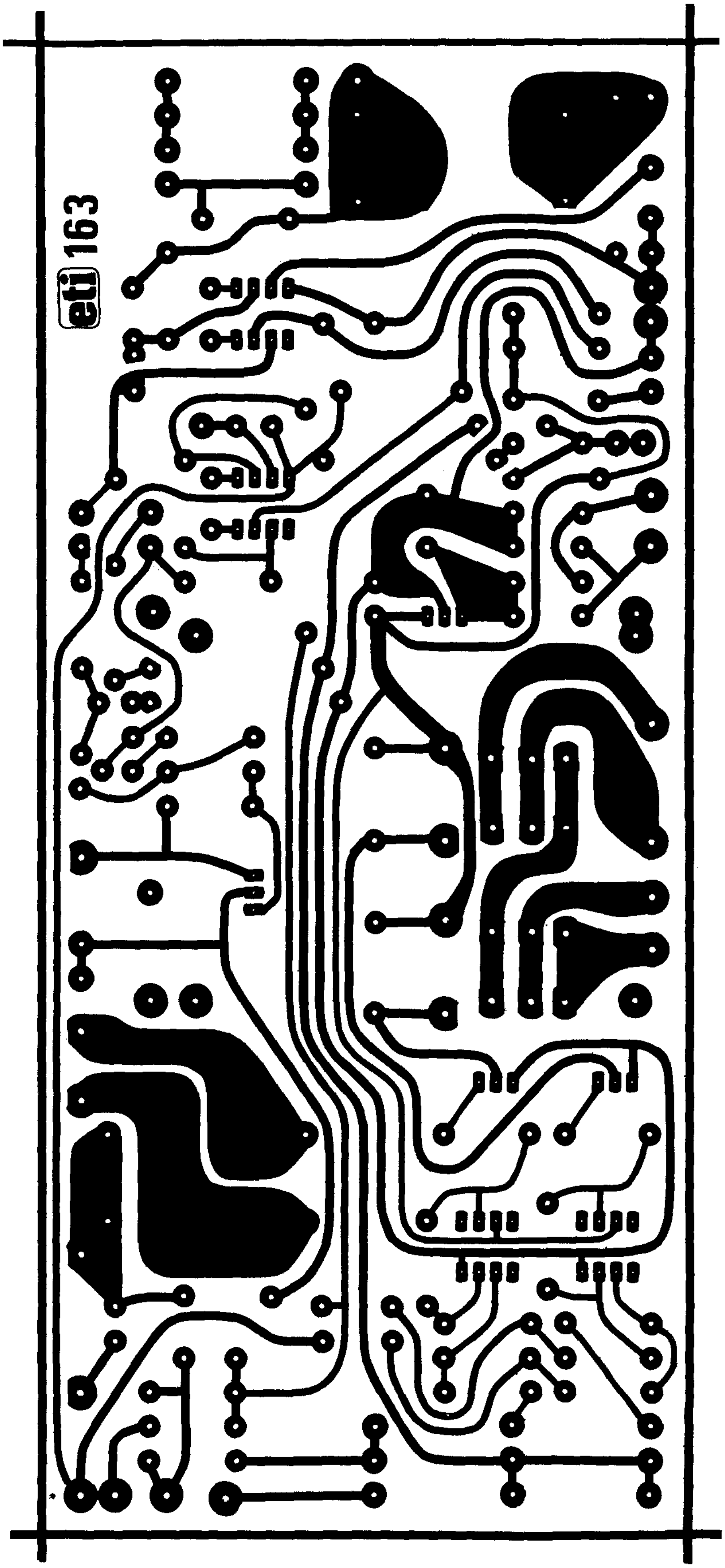
With a little experimentation and experience, you'll soon learn how to set up and effectively use the ETI-163 Lab. Supply. ●

Artwork. Here is full-size artwork for the pc board and the two meter scales. Unfortunately, the artwork for the front panel is too large to reproduce here. A photostat can be obtained by sending us a stamped-addressed A4-sized envelope. Scotchcal and pc board suppliers are listed on our Shoparound page.

You can obtain 1:1 positive or negative film of all the artwork for this project for $15 post paid from **ETI-163 Artwork, ETI Magazine, P.O. Box 21, Waterloo NSW 2017.** Make cheques or money orders payable to 'ETI Artwork Sales' and ensure you ask for **positive** or **negative** film, as you require.







Pushbutton-operated windscreen wiper controller

Windscreen wipers always wipe either too frequently or not frequently enough. This is a corollary of Murphy's law. Vehicle engineers have spent much creative thought and effort on solving this problem since vehicles had windscreens and covered cabins. Knobs and switches abound. This one simply requires a push or two on some buttons and gives you the exact wiping frequency you need.

Geoff Nicholls
Roger Harrison

THE CIRCUIT for this project won the 'Idea of the Month' contest, sponsored by Scope Laboratories, for the Sept. '82 issue of ETI. A reader from Herston in Queensland, who only wished to be identified as J.D.W., submitted the circuit. It is probably one of the most intriguing circuits ever submitted for the contest. Not only that, it solved a practical problem in an elegant and intriguing way.

As the introduction says, windscreen wipers either wipe too frequently, or not frequently enough. As most late-model cars are fitted with dual-speed wipers, at high speed they're making setting-teeth-on-edge noises after half a dozen wipes in the high speed position or not getting rid of the water fast enough in the slow speed position, in any given downpour.

Vehicle manufacturers, in our opinion (and experience), have never adequately addressed themselves to the problem. Two-speed wiper systems are legion. And what driver of a vehicle with a two-speed wiper has *not* mentally labelled the two speeds 'too slow' and 'too fast'.

A 'fully variable' system has long been considered the best solution. With these a rotary control provides a variation in wiper speed from a wipe every few seconds to a few wipes per second (maximum motor speed). That's fine, but you have to mentally 'calibrate' the control. At slow wiping speeds, this is a difficult task and you spend some considerable time fiddling with the control. Inevitably, you give up and take the 'that'll do' line of least resistance.

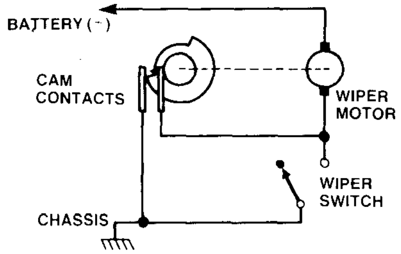


Figure 1. Self-parking arrangement for a wound field wiper motor.

Let us examine what happens when you're driving along and it starts to rain. First thing, the windscreen gets wet. When it gets wet enough, you want it wiped. You start the wiper and it does its job. Some interval later, the windscreen gets wet enough that you want it wiped again. *That's* the interval at which the wipers should operate. How on earth does one design a control that does that? The answer is, you don't. What you need is a controller with a 'memory'. Press a button to wipe the windscreen when it first gets too wet for you, then press it again when the windscreen next gets too wet, and have the controller repeat the wipes at the same interval. That's what the memory does — remembers the interval between the first two wipes.

What to do when the rain increases? Simply press the button again between wipes, setting a new interval. How do you stop it when the rain stops? — simple, have a stop button!

What to do when the rain decreases? Aahh — thought you'd ask that. Hit the stop button, but keep the memory going, then start the wipers again when the windscreen gets too wet, repeating the wipes at the interval between the last wipe and the new one.

That's exactly what this project does.

There's one final question to resolve, however. How long should the 'memory' be? Our correspondent set it at about 40 seconds. From observation, this seems about right. Driving in intermittent rain, we observed that the maximum interval between successive 'too wet' windscreens was about 30 seconds. During the latter half of 1982, Sydney turned on some very Melbourne-like weather — intermittent rain and shine, very light, 'patchy' rain, etc. The Editor cursed his dual-speed wiper and yearned for something better. Hence, this project.

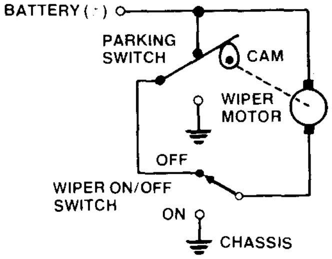


Figure 2. Self-parking arrangement for a permanent magnet wiper motor.

The circuit employs half a dozen ICs, two transistors, a handful of capacitors and around 30 resistors. A relay is used to control the operation of the wiper motors.

Before going on with the construction, let us take a look at the wiper systems in modern vehicles.

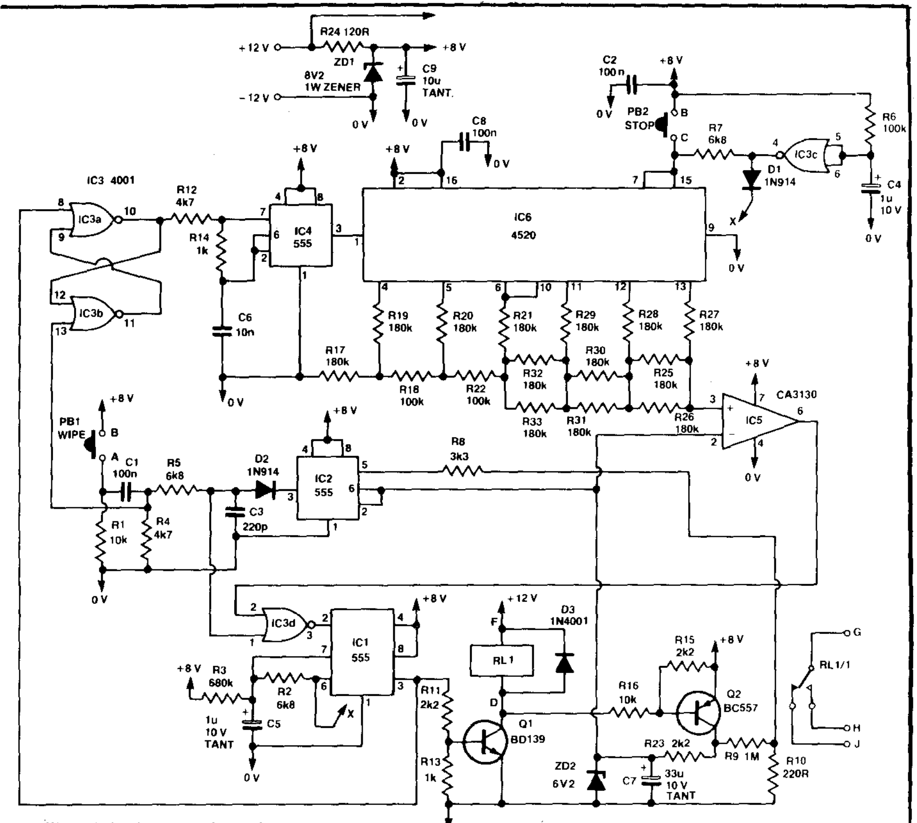
Wiper systems

With rare exceptions, windscreen wipers on modern vehicles are driven by an electric motor. Two motor types are employed — permanent magnet motors and wound field motors. The wiper systems are generally arranged so that the wipers are 'parked' out of the field of view when they're not in use. A cam-operated switch effects this, turning off the wiper motor only when the wipers are in the appropriate position and the supply to the motors is cut. However, the two different motor types have different braking characteristics when the motor supply is cut, so different switch schemes are used for parking.

Wound field motors simply have the supply cut when the wipers are in the appropriate position. A set of cam-operated contacts on the drive shaft effects this. Figure 1 shows how the arrangement works. The cam opens the contacts when the wipers are in the parked position. The wiper switch parallels the cam contacts. When you turn the wiper switch to the off position, the motor will continue until the cam contacts open.

Permanent magnet motors have 'dynamic braking' applied. A short circuit is connected across the motor armature when the wipers reach the parked position. The circuit is shown in Figure 2. Cam-operated changeover contacts are connected such that, when the wiper switch is set to the off position, the cam contacts short the armature. When power to the motor is cut, it becomes a generator, ▶

HOW IT WORKS — ETI-335



The best way to understand how this circuit works is to first look at the various circuit elements employed, then the step-by-step operation.

IC1 is a one-second monostable multivibrator that drives Q1. This operates the relay, RL1, the contacts of which operate the windscreen wiper motor.

IC1 is triggered via IC3d. Initially, pin 1 of this gate will be low (0 V), held down via R4 and R5. Pin 2 of IC3d will also be low initially. This is connected to the output of IC5 (pin 6) which will be at 0 V as its two inputs will initially be at 0 V.

IC2 has pins 2 (trigger) and 6 (threshold) tied together. Initially, they'll be low (below threshold), and the output (pin 3) will appear as an open circuit.

IC3a and IC3b form a flip-flop. This controls IC4, an astable multivibrator. The flip-flop inputs are pin 8 of IC3a and pin 13 of IC3b. Initially, both will be low and the flip-flop output will be low. Thus IC4 is disabled.

The output of IC4 drives the input of IC6, a dual binary counter with its two sections cascaded. Each counter has a 4-bit output. These outputs are connected to a resistor ladder network, making a 'stair step' generator. Thus, the voltage on pin 3 of IC5 rises in small 'steps' as IC4 oscillates, stopping on the last step when IC4 ceases to oscillate, providing a voltage 'memory'.

Now, let us see what happens when the WIPE button is pressed for the first time.

Operating PB1 puts a voltage pulse across R1. As C1 is discharged, this pulse appears across R4 and thus a logical high ('1') appears on pin 1 of IC3d. The output of IC3d (pin 3) will initially be high, going low (0 V) when pin 1 goes high. This triggers IC1 and its output, pin 3, goes high for a period of one second.

This turns Q1 on and the relay will be held operated for one second, causing the wiper motor to operate. The wiper will complete one wipe and, as it takes longer than one second, the relay will have dropped out by the time the wiper returns to the start position and the wiper motor will thus 'park'.

When Q1 turns on, its collector goes low and Q2 will be biased on via R15-R16. Thus, C7 will charge rapidly via R23. It can only charge to a maximum of 6.2 volts, limited by the zener diode ZD2.

After IC1 has completed its one second timing cycle and Q1 turns off, Q2 will turn off and C7 will discharge slowly via R9-R10, taking about 40 seconds. The voltage across R10 provides a small voltage which is applied to the 'control' pin (5) of IC2, which affects the threshold level at which IC2 can be triggered.

The flip-flop, IC3a-b, remains unchanged when PB1 is first pressed. Both flip-flop inputs (pins 8 and 13 of IC3) go high immediately PB1 is pressed, and thus the flip-flop output will remain low and IC4 will remain disabled.

When C7 is charged, and while it remains sufficiently charged, IC2's trigger-threshold pins (2 and 6) will be above the threshold and pin 3 will pull the cathode of D2 low (almost to 0 V). At the same time, the inverting input of IC5 (pin 2) will be held at the same voltage as is on C7 and its output will be driven to 0 V.

If the WIPE button is pressed again within 40 seconds of the first press, a voltage pulse will appear across R1 and R4, as before, but this time pin 1 of IC3d is held low by the output (pin 3) of IC2, via D2. Thus, IC1 won't trigger via this means.

However, as pin 8 of IC3a (one flip-flop input) is held low via R11-R13, the voltage pulse across R4 will appear on the other input of the flip-flop, pin 13, changing its output (pin 10/12) from low to high. Thus, IC4 is enabled and will commence to oscillate.

As IC4 oscillates, the stair step generator will rapidly drive up the voltage on pin 3 of IC5. When it reaches the same voltage as that on pin 2, the output of IC5 will immediately go high (jump to +8 V), driving pin 2 of IC3d high. Pin 3 of IC3d will then go low, triggering IC1. Thus, Q1 operates the relay once again and the wiper wipes.

When IC1 triggers this time, pin 5 of IC3a will go high and the flip-flop output will go low, disabling IC4 and stopping the count in the 4520. The output voltage of the stair step generator will thus stop at that point — providing a 'memory' of the voltage left on C7 after it discharged for the period between the first and second presses of PB1.

When Q1 turns on again, Q2 will turn on again, charging C7, raising the voltage on pin 2 of IC5 above that on pin 3. This will now drive the output of IC5 to 0 V once more, setting pin 3 of IC3d high once again, restoring the initial conditions.

After IC1 completes its timing period, Q1 and Q2 will turn off and C7 will begin to discharge again. When the voltage on C7, and thus the voltage on pin 2 of IC5, drops to that held on pin 3 by the stair step generator, the output of IC5 will go high, triggering IC1 via IC3d, as before, and the whole cycle will repeat at that interval it takes for C7 to discharge to the voltage 'remembered' by the stair step generator.

You can shorten the interval at any time by pressing PB1 between wipes.

To stop the wipe sequence, press PB2. This puts a momentary high on the 'master reset' inputs of both counters in IC6 (pins 7 and 15). All outputs are then reset low. This drops the voltage on pin 3 of IC5 to 0 V, its output then going to 0 V, setting IC3d to the initial conditions.

IC3c provides a 'power-on reset'. This ensures that the controller does not operate the wipers when the ignition is turned on and power is applied to the unit. It works like this: Capacitor C4 will be initially discharged, holding the inputs of IC3c low. When power is applied to the unit, pin 4 of IC3c will immediately go high. This drives the master reset inputs of IC6 high via R7, ensuring all the outputs are low, and also drives the threshold input of IC1 (pin 6) high via D1, preventing IC1 from operating and holding its output (pin 3) low. Thus Q1 and RL1 cannot operate.

Capacitor C4 will slowly charge via R6 and when the voltage across it reaches the high threshold (about 4 V, ±1 V) of the IC3c inputs (pins 5, 6) the output, pin 4, will go low, readying IC6 for counting. Diode D1 will now be reverse biased and IC1 will be ready for operation.

That covers the general operation, but there are a few more details you'll need to know for better understanding of its operation.

Firstly, the period of IC1 is determined by R3 and C5. The actual period is not critical, so close tolerance components are not necessary here.

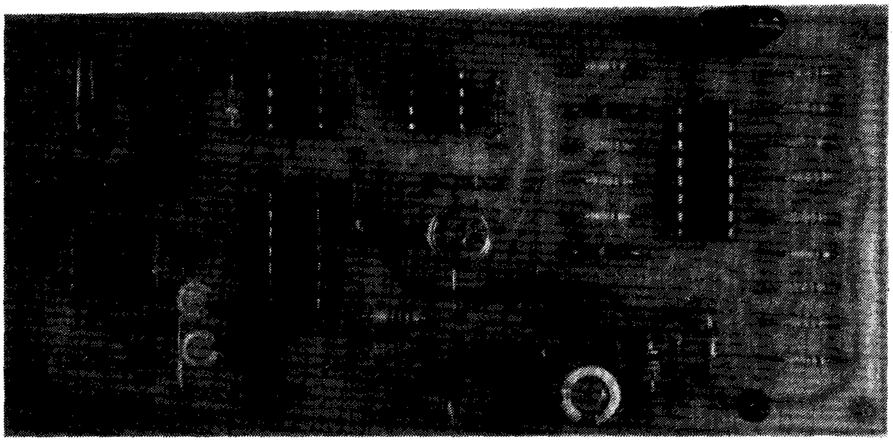
The frequency at which IC4 oscillates is determined by R12, R14 and C6. This is about 2 kHz. Here too, the exact frequency is not important, it simply means that at that rough frequency, the stair step generator output steps up to the required level very rapidly.

The RC network consisting of R1-C1-R4 is there simply to provide a pulse. When PB1 is pressed, C1 will initially be discharged, so the voltage across R4 will rise instantly to 8 V. But C1 will charge fairly rapidly and the voltage across R4 will die away quickly. The RC network of R5-C3 is an integrator which 'cleans up' the pulse from PB1. Contact bounce in PB1 may prevent reliable operation of IC3d and thus IC1.

Diode D3 shorts out the back-emf of the relay coil when Q1 turns off, protecting Q1 from collector-emitter reverse voltage breakdown.

The +8 V supply is provided by a simple zener regulator consisting of R24 and ZD1. Capacitor C9 provides supply rail bypassing, as do capacitors C8 and C2.

The 'memory' interval is determined by C7 and R9. We do not recommend you vary R9 if you want to vary the memory interval. Vary the value of C7 instead.



Circuit board. The completed pc board. Note that some resistors are stood on end. The pc board pattern is reproduced on page 102.

current through the short circuit sets up a field in the armature which reacts with the permanent magnet field so as to produce a force opposing the rotation of the armature.

Connection of the wiper controller relay contact to the wiper system differs for each scheme, and this is covered later in the article.

Construction

Assembly of the project is quite straightforward. We recommend you use our pc board design. This avoids wiring errors and provides a robust mount for the parts. You can make your own pc board or buy one ready made (see the 'Shoparound' page in this issue). We'll assume you're using our pc board.

All the electronic parts are mounted on the board. The relay and two pushbuttons are mounted elsewhere, in convenient places in the vehicle. Tackle the pc board assembly first. Before commencing assembly, go over the board looking for broken tracks, small 'bridges' between tracks — particularly where they run close together and between IC pins. Also look for holes that haven't been drilled. If, or when, all is well you can tackle the assembly.

There are a total of 11 links on the board. We did this to avoid the expense of a double-sided pc board. Nine of the links are simply straight 'straps' using 22 gauge tinned copper wire (identified by dotted lines on the overlay). The other two are 'flying wire' links — one on the top side of the board (the black, snaky line on the overlay), the other underneath IC6 (shown in the accompanying photograph). Install the tinned copper wire links first. Note that one runs beneath IC5 and another beneath IC6. The flying wire links use insulated hookup wire and are installed later.

With the links in position, all the resistors can be soldered in place. The overlay has been laid out so that component placement is easily identified. Component numbers start in the top left hand corner of the board and go down, then across the board in increasing number. The last resistor (R33) is at the bottom right of the board.

Solder the capacitors in place next. Follow with the two 1N914 diodes, ZD1 (8V2), ZD2 (6V2), Q1 (BD139) and Q2 (BC557). The diodes and transistors have to be correctly oriented. Check which way round they go by looking at the component pinouts and the board overlay.

Now solder IC1, IC2, IC4 and IC5 in place. These are all in 8-pin packages. ICs 1, 2 and 4 are all 555s, while IC5 is a CA3130. Note that all ICs are oriented the same way, with pin 1 toward the 'top' of the board. Last of all, solder IC3 and IC6 in place. These are both CMOS ICs. Only handle them with your thumb and forefinger, holding the package by the ends so as to avoid touching the pins. If you're new to project assembly, a metal IC insertion tool is a great help. Solder pins 7 and 14 of IC3 first, then the other pins. With IC6, solder pins 9 and 16 first, then all the other pins. Do not use IC sockets as vibration in a vehicle can 'jog' the ICs out of the sockets.

Now you can install the flying wire links.

Connection between the board and the external components, the relay and pushbuttons, is made via a six-way terminal block. At this stage, you're going to have to work out where everything is to fit in your vehicle. You've probably already done that, anyway. You could temporarily hook things up and try it out (without connecting the relay contacts), just to see if it works and to sort out any possible troubles before finally installing the unit.

When testing it out, check that it works as described and see that the between-wipes 'memory' is at least 30 seconds. This will vary somewhat from unit to unit, because of the tolerance range of C7 and R9. That doesn't really matter, just so long as the maximum interval is about 30 seconds.

We mounted the pc board in a conveniently sized jiffy box and tucked it away under the dash. A 50 x 90 x 150 mm box will comfortably accommodate the board. Mount the six-way terminal block on the outside and inscribe the box with the A-B-C-etc terminal designations. The WIPE and STOP buttons can be mounted in any convenient position on the dash — either by drilling holes in the dash or mounting them to a box or bracket which is then affixed to the dash.

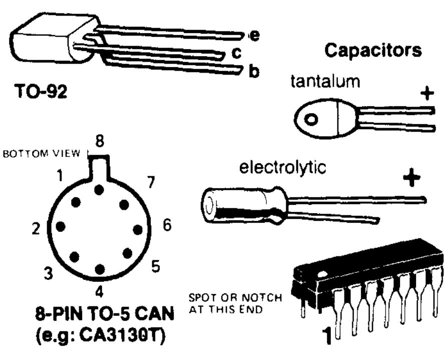
For the pushbuttons, you'll find the larger variety better to use, not the miniature ones. Both PB1 and PB2 are momentary-contact (SPST) types. Dick Smith Electronics stocks a suitable type, catalogue S-1199, as do Altronics (catalogue no. S 1080) and Electronic Agencies (catalogue no. SE0252). All these have a 15 mm square button (you can have any colour you like, so long as it's red) and require a 12 mm mounting hole.

The relay, as originally suggested by J.D.W., can be mounted in the engine compartment. This means you don't hear it going 'click-clock' all the time when the wipers are in use. Any standard 12 V relay with a set of changeover (SPDT) contacts rated at 5A at least can be used. If you can find one with lugs that take automotive-type slip-on spade connectors, so much the better.

Don't forget to wire D3 across the relay coil. You could, if you like, mount D3 on the six-way terminal block. (No, we didn't forget to include this on the board. It's just that, as the board was getting pretty cramped, it was more convenient to mount D3 off the board.)

Secure the relay firmly with a bracket. Use medium or heavy duty hookup wire (10 x 0.2 mm or 24 x 0.2 mm) to wire in the relay and pushbuttons.

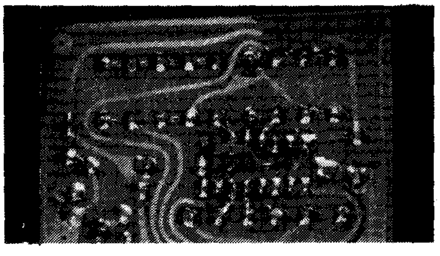
COMPONENT PINOUTS



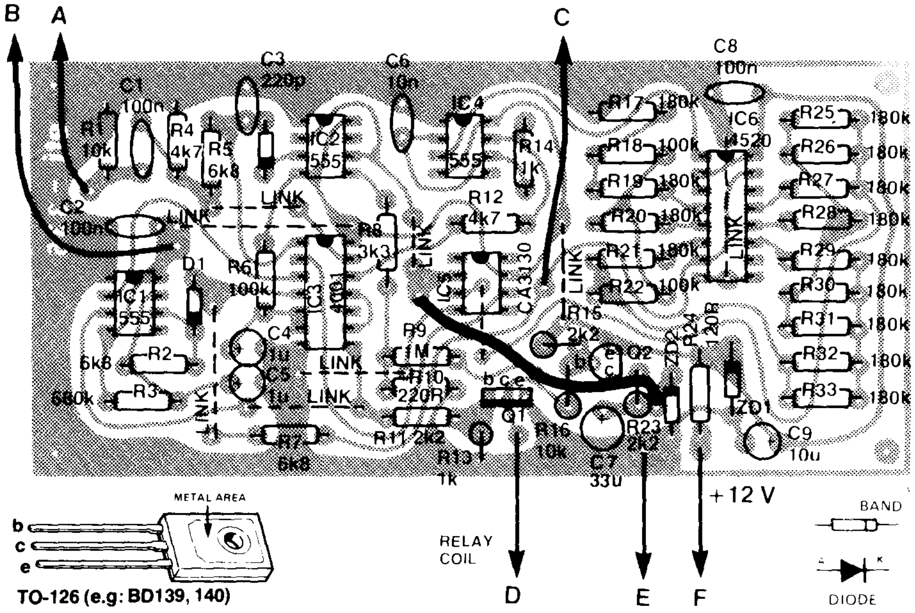
Wiring it to the wiper system

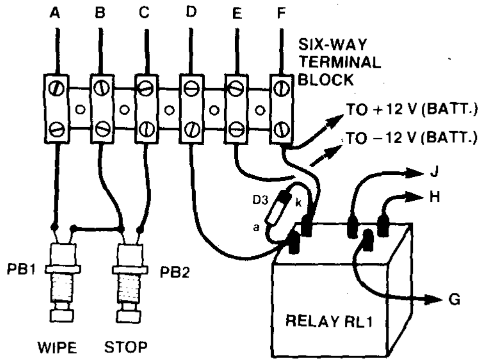
The general wiring schematics for single- and dual-speed wiper systems employing wound-field motors are shown in Figures 3 and 4. In each case, the *normally open* relay contacts of the controller are wired in parallel with the parking switch. Trace the wiring between the wiper motor and the switch. For the type of system shown in Figure 3, the switch will have two wires running between it and the wiper motor. It should be an easy matter to sort out which wire is which and to connect the relay contacts accordingly.

The dual-speed system shown in Figure 4 will have three wires running from the wiper switch to the motor. Grounding lead 1 should set the wipers going in 'high speed', grounding leads 2 or 3 should set the wipers going in 'low speed'. You can connect the normally open relay contacts (G and H) from 2 or 3 to chassis, or from 1 to chassis. In the latter case, you can operate the wipers right up to maximum speed.

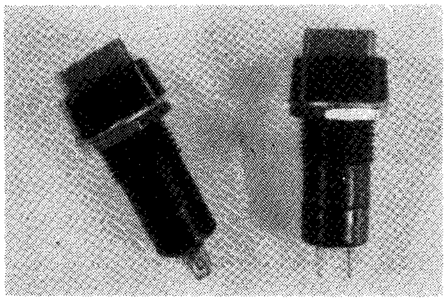


Underside link. Rear view (copper side) of the board showing the link between pins 6 and 10 of IC6.





Wiring. The board is wired to the pushbutton, relay and supply via a terminal block. The +12 V goes via an ignition-switched fuse (−12 V for +ve earthed cars). The relay contacts connect to wiper system.



Buttons. The two pushbuttons we used. Miniature types are not recommended.

PARTS LIST — ETI-335

Resistors .... all 5%, ½W unless noted

R1	10k
R2, 5, 7	6k8
R3	680k
R4, R12	4k7
R6, 18, 22	100k
R8	3k3
R9	1M
R10	220R
R11, 15, 23	2k2
R13, R14	1k
R16	10k
R17, 19, 20, 21, 25-33	180k
R24	120R

Capacitors

C1, 2, 8	100n ceramic
C3	220p ceramic
C4	1u/10 V axial electro.
C5	1u/10 V tant.
C6	10n ceramic
C7	33u/10 V tant.
C9	10u/10 V tant.

Semiconductors

IC1, 2, 4	555
IC3	4001
IC5	CA3130
IC6	4520
ZD1	8V2 1 W zener
ZD2	6V2 1 W zener
Q1	BD139
Q2	BC557
D1, D2	1N914, 1N4148
D3	1N4001, 1N4002 etc.

Miscellaneous

ETI-335 pc board; RL1 — SPDT relay with 5 A contacts and 180 ohm (or greater) coil (e.g: Dick Smith S-7125, or similar); PB1, PB2 — momentary contact pushbuttons (e.g: Dick Smith S-1199, or similar); 6-way terminal block; box to suit — 50 x 90 x 150 mm (if necessary); hookup wire, nuts, bolts etc.

A dual-speed permanent magnet system is illustrated in Figure 5. Here, the wire from the wiper switch to the parking contacts (3) is cut at X-Y and the wiper controller's *normally closed* contacts (J and G) connected across the cut. The normally open contact (H) is connected to chassis. If you need maximum wiper speed when using this system, simply use the wiper switch as you normally would.

In most instances, the chassis (earth) contact for the wiper switch is made through the body of the switch. Those systems which include a washer system where the washer is activated by pushing the wiper switch will have an extra wire for the washer. Some systems, usually found on British cars, are arranged to operate independently of an earth (i.e: do not use the vehicle chassis as a return lead) so that they may be fitted to either positive or negative earthed electrical systems. In such cases, you'll find a fifth wire extended from the wiper switch to the wiper motor, as indicated in Figure 5.

The installation of this wiper controller in no way alters normal operation of the wipers via the wiper switch installed in the vehicle. ●

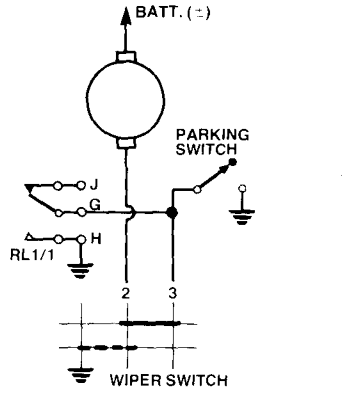


Figure 3. Wiring the relay contacts to a single-speed wound field wiper system.

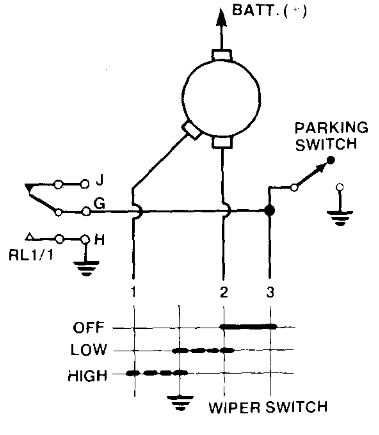


Figure 4. Wiring the relay contacts to a dual-speed wound field wiper system.

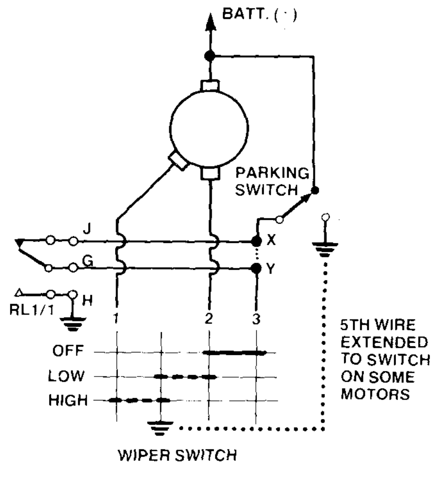


Figure 5. Wiring the relay contacts to a dual-speed permanent magnet wiper system.

A 'float' charger for NiCad batteries

This NiCad battery charger provides a happy medium between fast chargers and constant-current chargers. It's cheap, simple to build and will bring a battery to full charge from complete discharge in 12 hours — then keep it there. And your NiCads are safe from overcharging damage.

Jonathan Scott

AS YOU MIGHT INFER from the great range of chargers available and the number of projects describing them appearing in this and other magazines (should you ever read one, accidentally) there is more to charging NiCads than meets the eye. NiCads are rather finnicky things to deal with in that they basically require fairly continuous attention. The very best conditions are simply *use:* if you discharge and charge a set of NiCads once a week or so, they deliver hundreds of cycles quite happily.

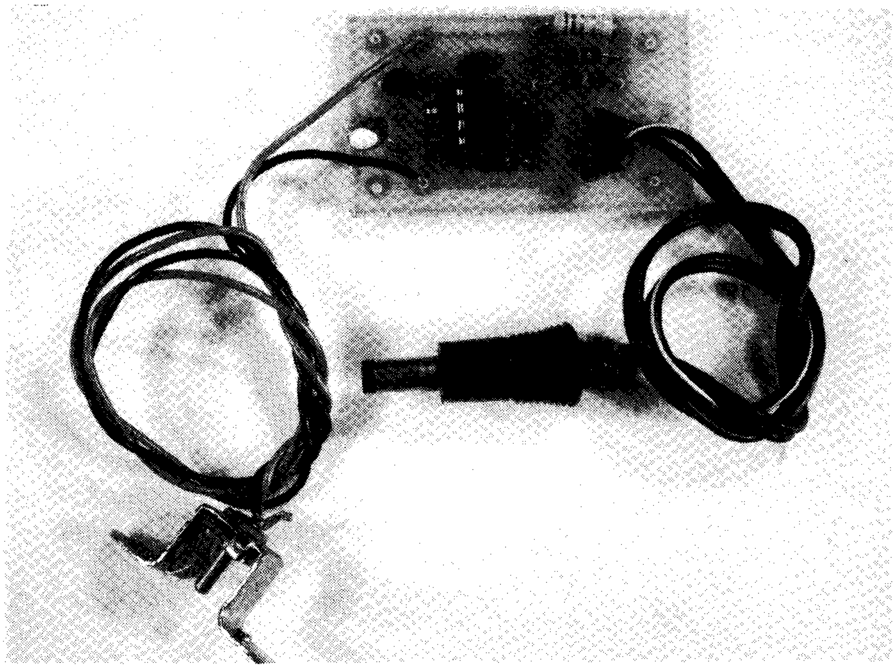
However, this is not the case in many typical applications. They may be unused for weeks or months in the flashgun of your camera or as battery backup in instruments. They may, on the other hand, be left trickle-charging endlessly and never discharged more than 10%, as is the case in a torch used for two minutes every week. Neither form of disuse is good. You can get fast chargers, such as the ETI-563, or the recommended controlled current source type which will charge at the ten-hour rate, or very low current trickle charge types such as are incorporated in some electric toothbrushes or small torches. Trickle chargers are safe in that the NiCads are not actively harmed no matter how long you leave them connected, but the cells take three days to recover a full charge. The controlled current sort are able to charge a cell right up in about 14 or 15 hours, but will upset the cells in about 24 hours if left on. Fast chargers are damn quick, and fairly safe if they are the type which turn off and you set them for the correct time, but are more costly and bulky.

Hence we present yet another alternative. This project will bring a set of cells up to full charge from complete discharge in about 12 hours and then automatically drop to a trickle whenever the charging is done. This means full recovery in half a day with safety from overcharging damage. Hence the title, 'Float Charger'.

The circuit presented here is specifically designed for penlight size batteries ('AA') and is arranged to charge four cells in series, which is the number generally found in portable cassette players, etc. You're not locked-in to this set of circumstances however. You can charge different numbers of cells of amp-hour capacities between 250 mAh (¼ Ah) and 1 Ah simply by selecting the values of three resistors according to Table 1. The project will charge up to four cells from a 10 volt supply. For each additional cell, the supply needs to be increased by 1.5 V. i.e: six cells need 13 volts supply.

Although the project will charge cells of up to 4 Ah capacity it will work at full rate only on cells up to 1 Ah, but this is not a serious problem as most small appliances and backup systems use quarter or half amp-hour types.

The project can be incorporated inside a piece of equipment or it can be built into some dedicated charger at very little cost (under $10) and will run off any power supply of 10 to 22 volts (according to what's required), e.g: a plugpack, car battery, power supply, etc. In addition, there are no controls or presets to adjust at all. Some chargers of this type require calibration against a digital meter or similar, but this one is born calibrated. It may be fabricated on its own pc board or incorporated in the power supply of something you are building.



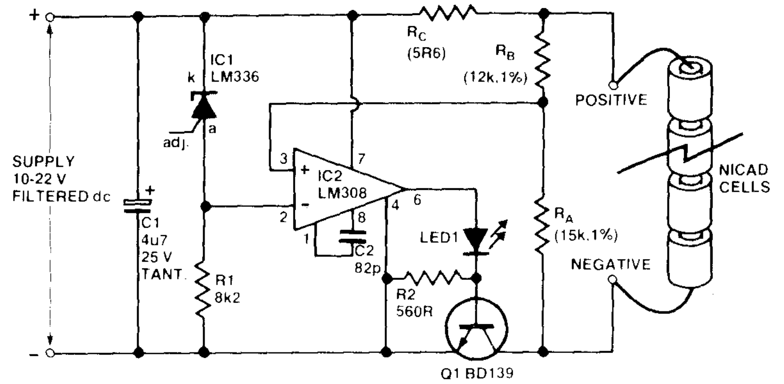
Simplicity plus! A handful of components, a 30 x 50 mm pc board . . . and no complications.

Construction

Construction of this project is largely left up to you as far as boxes and connectors go because of the many possibilities you have open. The prototype was left unencapsulated, and has been fitted with a plugpack receptacle on the input end and a similar plug on the output as it has been designed to go between a small cassette player and a plugpack originally provided to charge the cells inside the player. A car cigarette lighter plug could just as easily be fitted to allow use in a car. If you do not intend to use a carefully polarised input connector, a diode in series with the input is a good idea as the unit will be damaged if exposed to reverse polarity.

The first thing to do before constructing the project is to select values for the three resistors R_A, R_B and R_C according to Table 1, given the size (Ah capacity) and number of the cells to be charged. If your application has a number of cells not covered in the table, use the formulae given there to find values. ▶

HOW IT WORKS — ETI-268



The 'ideal' charger for NiCad batteries is a precision voltage source in series with a fixed resistance — where the voltage source is a little above the battery terminal voltage when fully charged. Thus, when a discharged battery is connected, the charge current is maximum, reducing to a 'trickle' when the battery is fully charged. That's what this project has been designed to do. It makes use of a low cost precision reference element, an LM336, and a comparator driving a series-pass transistor to control the charge current applied to the batteries.

The precision voltage reference, IC1, looks to 'the outside world' as a zener diode. The 'adj.' terminal permits adjustment of either the terminal voltage (over a very small range) or the temperature coefficient (how the terminal voltage drifts with variation in temperature). The 8k2 resistor, R1, provides current for IC1 which produces a fixed potential of between 2.390 V and 2.590 V below the positive supply rail at its anode. This is fed to pin 2, the inverting input, of the 308 (IC2) which is here arranged as a comparator.

The non-inverting input of IC2 (pin 3) is fed by a voltage that depends on the sum of the terminal voltage of the cells being charged and the current fed to them. Three resistors — R_A, R_B and R_C — sample the cell terminal voltage and charging current, providing a fixed sum of these variables. The output of IC2 drives the base of Q1 via LED1. Q1 controls the charging current fed to the cells. The sum of the voltage drops across R_C and R_B is maintained at the same voltage as that across IC1. As the terminal voltage of the cells rises with charging, the voltage drop across R_C will decrease, but the voltage drop across R_A/R_B will increase. The ratios have been set so that the drive to the base of Q1 decreases as cell voltage rises.

The LED between the base of Q1 and the output of IC2 serves two purposes. It provides the voltage offset required between the IC's output and the negative supply rail as the 308 cannot drive its output right down to the negative rail; and secondly, it gives an indication that the charger is operating. (You can check that the load is correctly connected by looking for an increase in intensity when connection to the cells is made). Resistor R2 keeps Q2 turned off when required and ensures that there is some current flowing in LED1 even when the load draws no current. Capacitor C1 removes any hash from the supply which might upset the 308 in a noisy environment. Capacitor C2 provides compensation for IC2.

Neither capacitor is critical in value, but C1 should be a tantalum type if you intend to run the charger in harsh electrical environments such as a car or near RF equipment. A 308 was chosen for IC2 as it has a very low offset voltage and a high input impedance.

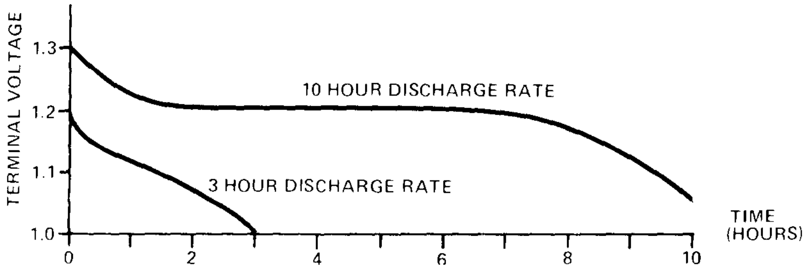
The output of the 308 is current-limited internally and since the load current is equal to the beta of Q1 times the current sourced to its base, the output is current-limited to a value of around 300 mA or so. If the charger output is likely to be shorted (or if the possibility exists), Q1 should be placed on a small heatsink, for safety's sake. Under normal operating conditions charging penlight (AA) cells, Q1 does not require a heatsink. Should you wish to upgrade the unit for higher charging currents, a Darlington-pair device should be substituted for Q1, with suitable heatsinking attached.

THE NICKEL-CADMIUM CELL (NiCad)

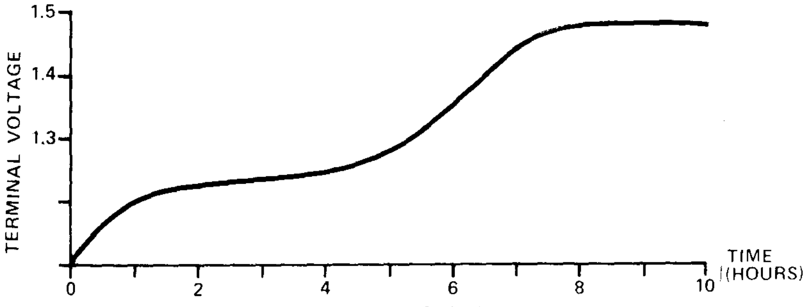
NiCad cells use a potassium hydroxide electrolyte. In a typical unit the positive and negative plates are both perforated steel. The positive plate is filled with nickel hydroxide, the negative plate with finely divided cadmium mixed with a little iron to prevent it flaking and losing porosity. The electrolyte has a specific gravity of 1.15-1.2, depending on the type of service. It does not undergo any chemical change during discharge. Very little electrolyte is needed and the positive and negative plates are very closely spaced.

NiCad batteries are made in a wide variety of sizes and amp-hour capacities. Miniature ones for use in cameras, calculators etc up to large heavy duty types similar to car batteries. They may be operated over a wide temperature range — similar to that of lead-acid batteries. At low temperatures, the amp-hour capacity does not diminish as much as with lead-acid batteries. However, the electrolyte may freeze.

As NiCad batteries may be sealed, they can be used in any position. The no-load terminal voltage of a nickel-cadmium cell is typically 1.3-1.4 volts. This drops to about 1.2 volts under load, and to about 1.1 volts when discharged. As the electrolyte does not change during discharge (as it does in lead-acid batteries), the number of amp-hours obtained from a NiCad battery is much less affected by the discharge rate than are lead-acid batteries.



Going down. Typical discharge characteristics of NiCad cells..



Juicing up. Typical charging characteristics of NiCad cells.

As NiCad batteries can be made quite small, and can be recharged, they are eminently suitable for use in portable electronic equipment such as calculators, tape recorders, hand-held transceivers, camera flash units etc. They can withstand considerable vibration, are free from sulphating or similar problems, and can be left in any state of charge without ill effect.

Charging should be done with a constant-current charger. The charging rate for the quickest charge should be no more than 1.5 times the 10 hour discharge rate. Most manufacturers recommend a charge rate and a trickle or 'float' charge rate and this is best adhered to.

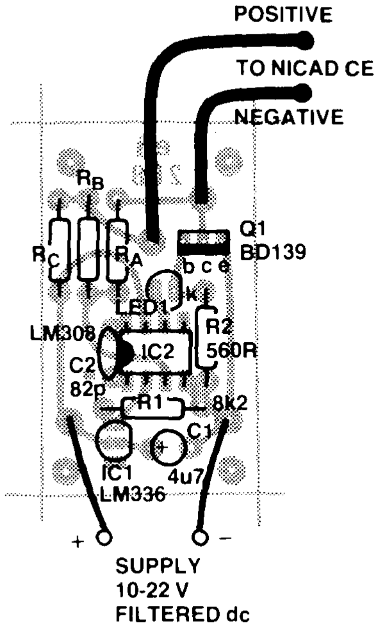
PARTS LIST — ETI-268

Resistors	all ½W, 5% unless noted
R1	8k2
R2	560R
R_A	15k, ¼W, 1% see Table 1
R_B	12k, ¼W, 1% see Table 1
R_C	5R6 see Table 1
Capacitors	
C1	4u7 or 10u 25 V tantalum
C2	82p ceramic
Semiconductors	
IC1	LM336
IC2	LM308, uA308 (or /A)
LED1	RL209R miniature red LED, or similar
Q1	BD139

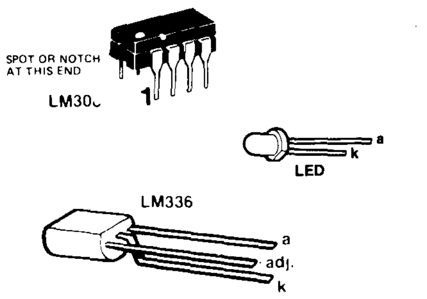
Miscellaneous

ETI-268 pc board; supply input and charger output connectors to suit (see text); small heatsink (see text) if necessary; hookup wire etc.

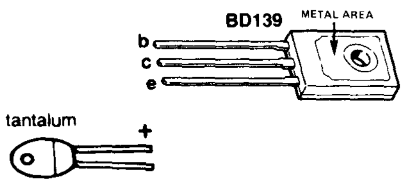
Price estimate
$7 — $8



Overlay. Showing component positioning on the pc board. Components are placed on the non-copper side of the board. Watch the orientation of C1, IC1, IC2, Q1 and LED1. Check these with the component pinouts.



IC1. The LM336 is available in a plastic case, similar to the TO-92 style and marked LM336Z or LM336BZ, or in a metal case, like a TO-39 style and marked LM336BH. The plastic-cased variety is most common and cheaper. Above is the pinout, showing lead connections.



PCB ARTWORK PAGE 64.

Next, fit the components to the pc board according to the overlay, being sure to get the ICs, LED, transistor and tantalum capacitor the correct way around in each case. If you intend to charge cells larger than penlight size, or there is a possibility of more than momentary shorting of the output, leave enough length in the leads of Q1 and fit a small heatsink, about 2 cm² in area.

Mounting holes have been marked on the pc board if needed so it can be attached to a chassis.

Once assembled, fit the wires and connectors. A small clear or amber plastic pill bottle makes an excellent case for this project if no particular location is necessary. The wires can be knotted and slipped through two small holes in either end.

Turn on

Apply power and see that LED1 illuminates. If not, switch off and check the LED orientation and the supply polarity. Fix any faults and start again. Then connect the cells. A small increase in brightness of the LED should be noticeable as you make the circuit.

Note that you cannot normally judge correct operation by inserting a current meter in series with the batteries as this upsets the sensing by virtue of the slight voltage drop across the meter terminals. Instead, measure the voltage across R_C, and divide by the resistance to determine current flowing. ●

TABLE 1

(A)

Cell capacity	R_C
250 mAh	12R
500 mAh	5R6
1000 mAh	3R3

(B)

No. of cells	R_A	R_B	Supply (min.)
2	1k5	10k	10 V
4	15k	12k	10 V
6	68k	27k	13 V
10	56k	12k	19 V
	¼W,1%	¼W,1%	

CALCULATION OF VALUES

Make R_B a convenient value below 100k

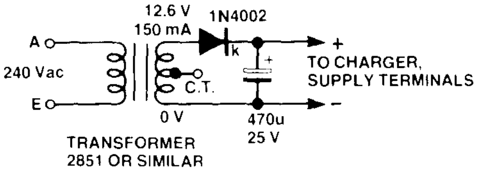
then, $R_A = R_B\left(\frac{C}{1.754} - 1\right)$

where C is the number of cells.

Go through the routine, reselecting a new value for R_B, if R_A does not come out within one or two per cent of a common value.

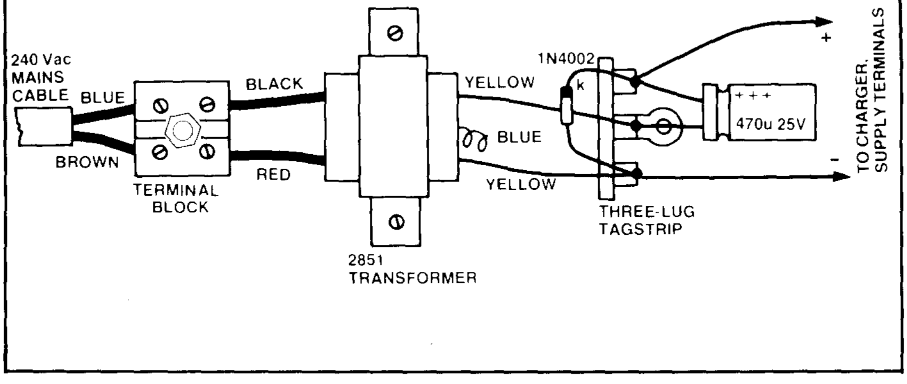
$$R_C = \frac{3}{I_{nom.}}$$

where $I_{nom.}$ is the nominal 10 hour charge rate.



CIRCUIT OF A SUITABLE POWER SUPPLY

SUGGESTED CONSTRUCTION OF POWER SUPPLY



Speed controller for appliances powered by a 'universal' electric motor

Electric drills, saws, grinders, food blenders etc, all benefit from having some sort of control over their speed. Simple electric motor speed controllers, while providing speed control, have limited ability to maintain motor speed constant over widely varying loads. This project overcomes the limitations of these simple units and, despite its simplicity and low cost, is remarkably effective.

Jonathan Scott

JUDGING BY users' remarks on the shortcomings of speed controllers on a variety of electrically driven appliances, and from much personal experience and observation, there is a *considerable need* for a well-designed speed controller for use with electric drills, grinders, saws, food blenders and other appliances driven by 'universal' electric motors.

The more expensive power drills now come with a variable control built into the trigger. Food blenders come *festooned* with an array of buttons marked with a ludicrous range of words with every synonym from 'mix' to 'masticate' represented!

These gadgets all have a severe limitation, namely, that they really only have voltage controllers, not speed controllers, for the motor in the unit. They vary the speed but provide little or no feedback speed control.

In the case of the power drill with a speed control in the trigger, the operator is in a position to adjust the trigger continuously in response to variations in the speed of the shaft, thus effectively becoming part of a feedback loop and serving as the speed *regulating* element.

The variable speed function of these latest drills is really not designed to allow the slow steady pace needed for delicate or laborious jobs, but to allow the unit to act as an electric screwdriver, when fitted with the appropriate bit, where constant speed is not necessary.

Blenders, however, are items which you typically want to turn on and add more and more ingredients (adding more load) as the process progresses. What happens? The jolly blender slows down as the load increases and it's a real bother to have to keep adjusting it. If you're not careful, or in too much of a hurry, you can stall the motor quite easily.

Older electric drills and most high rpm grinders never had any sort of variable speed adjustment, electrical or mechanical. Grinders fitted with a special 'pad' wheel are used for buffing, too. But you have to be quite deft, otherwise it's easy to buff right through the undercoat of a painted object because of the ferocity of the thing.

If you need to drill a particularly tough substance with an older drill, then you have to be prepared to wear out the fine, sharp drill tip very quickly.

So, there is a distinct requirement for some device which can be placed between the appliance plug and the mains that can be used to not only *set* the motor speed, but to *regulate* it as well.

The perils of simplicity

There seems to be fundamentally three degrees of complexity in the way one can design these circuits, each with advantages and disadvantages. All techniques employ some method of sensing the motor back-emf and adjusting the power delivered to keep the back-emf relatively constant.

For the sake of attaching 'handles' to each fundamental technique, I shall dub them — the *crude/economical* method, the *refined/economical* method and the *complex/ultimate* method.

For this project I have chosen the middle course for reasons which will become apparent shortly.

The crude/economical method is the simplest and for that reason has an extraordinary advantage in that it has a low parts count. This sort of circuit requires a diode or two, a pot, a couple of resistors or thereabouts and little else apart from the SCR switching element (see Figure 1). Now, it is hard to beat this sort of economy, but such circuits have a few annoying limitations.

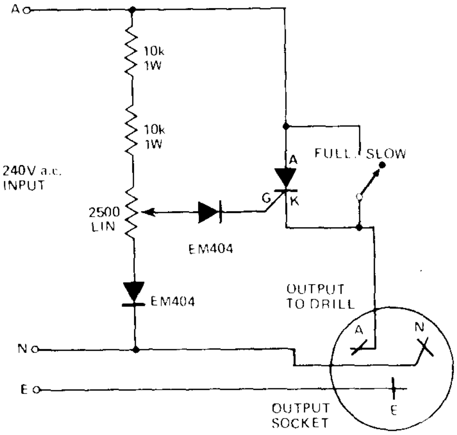


Figure 1. An example of the 'crude/economical' type of motor speed controller. This is the circuit of the ETI-525 Drill Speed Controller (Oct. '74).

Firstly, they will not usually drive anything but the most sensitive SCRs because they deliver very low gate currents. Secondly, some component values can be critical, resulting in touchy or erratic response if tolerances are a bit out or the unit is driving an unusual motor. Lastly, the lack of an amplifying element in the feedback means that the speed regulation, while being above normal for a universal motor, is nowhere near perfect and the speed does drop under load.

To separate the two further types of controller requires a reasonable familiarity with what goes on when controlling a universal electric motor, so I will discuss the technique I have used in this project now and then go on to the explanation of further refinement.

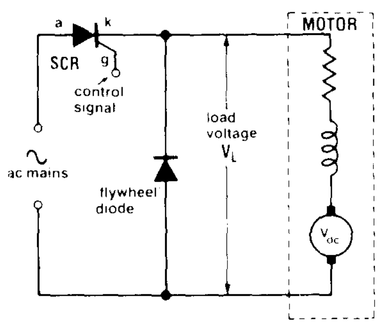


Figure 2. Fundamental circuit elements of the controller used in this project. Note that 'V_{dc}' is the back-emf of the motor.

Controller technique

A universal electric motor appears as a resistance, an inductance and a voltage source in series. The elements of the phase control system I have used — an SCR and a 'flywheel diode' — are connected as shown in Figure 2.

The voltage across the motor terminals during operation of this circuit will appear something like that shown in Figure 3. (Note that the vertical axis is not to scale.)

Considering the cycle from the peak onwards, let us examine the reason behind the appearance of each part of the waveform.

Say that, at some speed setting, the SCR is fired into conduction at about the 100° point of each positive half cycle. The load voltage jumps to a value very nearly equal to the mains voltage at that point (less the small drop across the SCR) and follows the mains cycle variation until the end of that half cycle (i.e. at the 180° point).

Thus, the point between 0° and 180°, of the positive half cycle, where the SCR fires, defines how much voltage is delivered to the load (the motor). Varying the delay before firing provides a means of varying the power delivered to the motor. This is known as phase control, for clearly obvious reasons.

At the point where the mains voltage falls below the back-emf voltage of the motor you would expect the current through the motor to become zero and the SCR to turn off. But, this is not quite the case as the load is not purely resistive. The inductive component of the motor forces its terminal voltage negative in an attempt to maintain motor current, and indeed, the load voltage would follow the mains negative for some way if it were not for the diode connected across the motor terminals.

This diode conducts as the motor voltage goes beyond about 0.7 volts negative and carries the 'flywheel' current from the motor's inductance, generated by the collapsing magnetic field, allowing the SCR to isolate.

The flywheel current persists until the energy stored in the motor's windings is exhausted. This takes typically two to five milliseconds.

Were the diode not there, a large negative-going pulse would result. This, in itself, is not a bad thing, but it is easy to block this and reduce the net dissipation in the SCR, allowing it to control a larger device for the same ratings and prevents the need to make the controller circuitry more complex to resist the negative-going voltage.

At any rate, some way into the negative supply half cycle, the inductance ceases to be the dominating voltage source within the motor and the back-emf becomes evident.

As you may see from the diagram, the motor voltage rises to a level defined by the apparent dc source within the motor equivalent circuit. (The 'back-emf generator'). This voltage is a result of residual magnetism in the metal of the armature and field coils and the relative motion of these two elements.

The actual back-emf developed depends on a number of factors, a major one being speed so it is a good representation of the motor's instantaneous speed.

There is some noise evident on the back-emf voltage, it is not a smooth dc level. This noise is partly due to commutation hash (high frequency spikes) and partly due to different amounts of residual magnetism in different armature segments etc. However, the noise is not sufficient to obscure the speed signal, or back-emf.

In a typical universal electric motor the back-emf would average around 10 volts at full rpm. The control circuitry in the

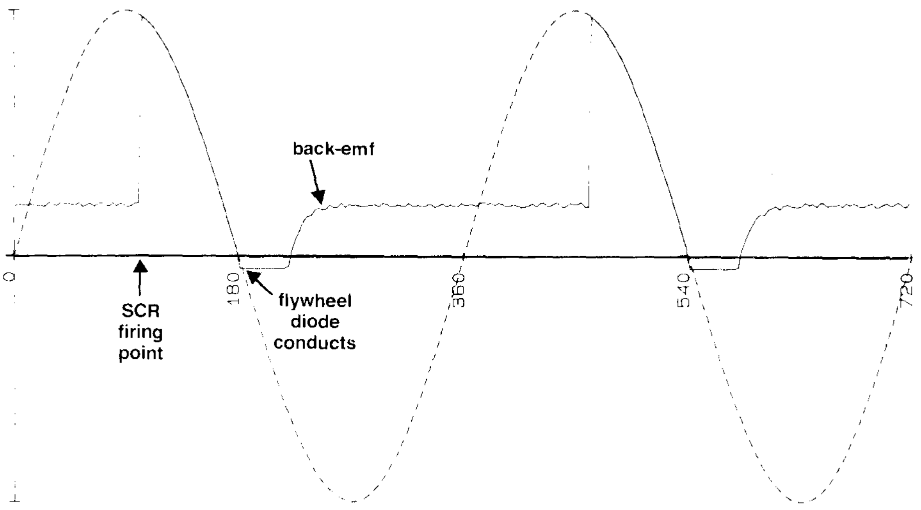
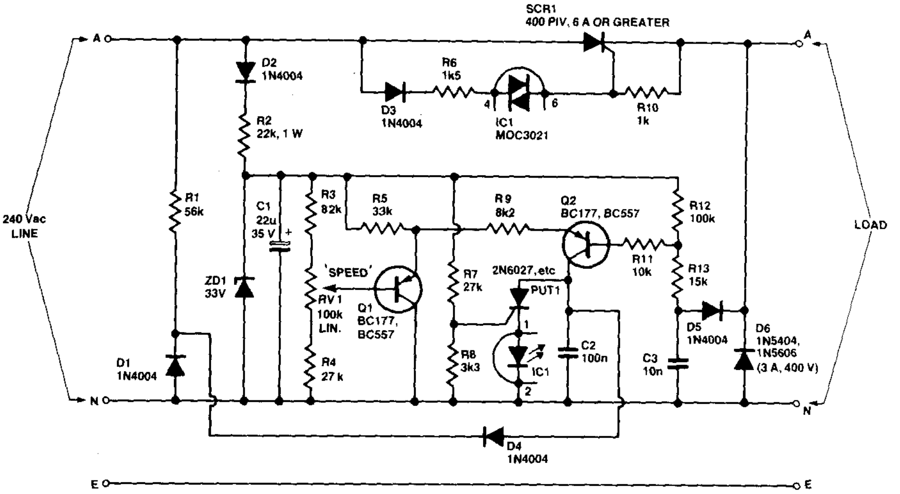


Figure 3. Waveform of the voltage across the motor when using the ETI-1515 speed controller. (Vertical axis not to scale.) The dashed line shows the mains input waveform.

HOW IT WORKS — ETI-1515



The speed of an appliance's motor attached to the project is controlled by applying the mains voltage to it at a set point of the mains positive half cycles, as seen in Figure 3. This is done by turning an SCR on at the appropriate point in the cycle. Turning on the SCR earlier in the cycle applies more voltage, increasing the speed, while turning the SCR on later applies less voltage, decreasing the speed.

The SCR (SCR1) is 'fired' by applying a positive pulse to its gate. This is effected by IC1, an optically-coupled triac driver containing a LED coupled to pins 1 and 2 and a bidirectional optically-operated 'switch' coupled to pins 4 and 6. When the LED in IC1 is off, the switch is off. When the LED is turned on, the switch conducts. If pin 4 is positive with respect to pin 6, it will forward-conduct from pin 4 to pin 6 and vice-versa if pin 6 is positive with respect to pin 4. So that only positive-going pulses are applied to the gate of SCR1, D3 ensures that the switch in IC1 can only conduct during mains positive half cycles.

Resistor R6 simply limits the current through IC1 pins 4 and 6 while R10 prevents false triggering of SCR1 due to small leakage currents.

The control electronics consists of Q1, Q2, PUT1, IC1, RV1 and associated components. The 'flywheel' diode is D6. Power supply for the control electronics is derived by a half-wave rectifier from the mains input. This consists of D2, R2 and C1. This supply is regulated by ZD1, a 33 V zener, R2 providing current limiting. C1 is charged up during the mains positive half cycles and substantially holds its charge during the negative half cycles.

The SPEED control, RV1 is part of a potential divider — R3/RV1/R4. The wiper of RV1 sets a reference level on the emitter of Q1. This can be anywhere between about 4 V and 15 V (with respect to the neutral line), depending on the setting of RV1.

Now, let us see what happens from the point where the mains positive half cycle crosses through the zero point, going negative, at 180° assuming SCR1 has been fired during the preceeding half cycle.

Referring to Figure 3, as the mains crosses through zero, going negative, D6 (the flywheel diode) will conduct, holding the active (A) load terminal at about −0.6 V. The SCR then becomes reverse biased and ceases conducting.

Capacitor C3 will have been charged to a certain voltage (via R12/R13) but will now be discharged via D5. Any charge on capacitor C2 will be discharged via D4/D1/R1.

Diode D6 remains conducting until the inductive backlash of the motor (as explained in the text) dissipates. The voltage at the load active terminal (with respect to the neutral line) then rises to the back-emf level. D5 is now reverse biased, allowing C3 to charge again via R12/R13 until it reaches the level of the back-emf + 0.6 V (D5's forward conduction voltage). Small positive-going 'spikes' on the back-emf level are ignored (momentarily reverse biasing D5) due to the time constant of R12/R13 and C3. This prevents erratic control circuit operation due to this noise. Nevertheless, small fluctuations are still present in the negative peak level held by C3.

Transistor Q2 is forward biased by the voltage drop across R12. The collector of Q2 sources charging current to C2, but this is held discharged via D4/D1/R1 until the mains negative half cycle crosses the zero point and the next positive half cycle begins. When it does, and D1/D4 are reverse biased, C2 will commence charging at a rate determined by the collector current of Q2.

The programmable unijunction transistor (PUT1) has its gate held at about 4 V (with respect to the neutral line) by the potential divider of R7-R8. When C2 charges to 0.6 V above this level, the PUT will 'fire', delivering a current pulse to the LED in IC1. This will operate the switch in IC1 and SCR1 will fire.

The rate at which C2 charges determines at what point in the cycle the PUT, and thus the SCR, will be fired. There are two mechanisms for determining the rate at which C2 charges, and thus the point in the cycle at which SCR1 is fired.

Firstly, a reference level is set at the emitter of Q1 by the setting of RV1, the speed control. The collector-emitter current of Q2 will depend on the value of the voltage at this point and the value of R9, assuming the base voltage is held constant. Thus, varying RV1 varies the charging rate of C2, setting the point at which SCR1 fires.

Secondly, the base current of Q2 varies (and thus the collector current) depending on the voltage drop across R12. If the back-emf of the appliance motor falls, such as with an increase in motor loading, the voltage held on C3 will decrease (pulled down by D5 conducting current through the load) until it reaches the new value of the back-emf plus 0.6 V (D5 forward drop). This will increase the voltage drop across R12 and thus increase the base and collector current of Q2. Thus, C2 will charge more rapidly each mains positive half cycle, firing the PUT and SCR1 earlier in the cycle. This applies more power to the motor so that its speed is maintained.

If the back-emf rises, such as it would from a decrease in motor loading, the voltage on C3 will rise and the voltage drop across R12 will decrease, decreasing the collector current of Q2. Thus, C2 in this case will charge more slowly, causing the SCR to fire later in the cycle. This will reduce power to the motor so that the set speed is maintained.

The function of R11 is simply to limit the currents in Q2 during those parts of the cycle when Q2 is not responding to the back-emf signal.

the delay if the motor attempts to slow down under increasing load.

In other words, if the motor is slowed by a heavy load the back-emf will drop and the control circuit will fire the SCR earlier in the cycle than where it was originally set to fire. This applies the mains voltage to the motor for a longer period, bringing the motor speed back up again. If the motor speeds up when load is reduced, the opposite happens.

Thus, the motor speed will be held constant. It sounds as if the motor will slow down then speed up, or vice versa, but the control variation actually happens within one mains cycle or so and any variation in motor speed will not be apparent.

Readers familiar with control theory will notice that this mechanism forms a control feedback loop. Within the control electronics of this project I have included some amplification which enables the unit, firstly, to drive even quite insensitive SCRs, secondly, to reduce the speed error to a relatively small value and, thirdly, to have a relatively high impedance presented to the reference level (speed) control which is a voltage produced by a potentiometer. This overcomes the limitations of the cruder controllers.

However, the controlled element is a mechanical system with a lot of inertia which represents a significant pole in the transfer function. Hence, it can be anticipated that there will be a trade-off: increasing the amplifier's effective gain will improve regulation all right, but if it is increased too far the system will become unstable and the engine speed will 'hunt', or oscillate about a mean value at a low frequency.

The perils of complexity

It turns out that, in the case of most motors, a very satisfactory degree of speed regulation can be achieved with only a hint of hunting detectable at *very* low speeds. This is most fortunate as it means that one does *not* require to advance to the next step of complexity, namely using the third technique mentioned earlier — the *complex/ultimate* circuity with its own compensating system incorporated to guarantee the stability of the system under *all* conditions, despite large loop gain.

The reason that this type of circuitry is to be avoided, for the applications considered in the introduction to this article, is that it would require a great deal more electronics (and cost!). This would basically entail ▶

a mechanism capable of smoothly holding the back-emf signal so it could be further processed, which means some kind of sample-and-hold gate plus some synchronising signal. Once isolated, the signal is easily dealt with, but the process is much more complex than the simple instantaneous method employed in the ETI-1515.

One further refinement in a complex/ultimate controller may occur to the astute reader: namely, having the circuit capable of using the full 360° (or very nearly) of the mains supply cycle. The systems described so far all assume that an SCR will be used to control the current delivered and not a triac. Hence, at most, only 180° of the mains cycle is available as the SCR must remain in a blocking state during the negative half cycle. Although a triac would permit use of the negative cycles, as would full-wave rectifying the mains before applying it to the SCR, these methods have one problem.

The sensing of speed, so that the speed may be regulated, requires access to the back-emf voltage, blanked immediately after a current zero. Hence, any attempt to employ near-continuous power application would be hampered by the inductive 'backlash' concealing the motor's true back-emf value. Any such system would have to be capable of operating in a mode which left only every fourth or sixth half cycle unemployed for the purpose of 'getting at' the back-emf for speed sensing.

While possible, this would not only require considerable circuitry, but would also tend to impart some roughness to the torque delivered. Hence, such methods are well abandoned for the applications for which the ETI-1515 has been designed. It is a realm of circuit complexity which returns benefits only with physically large machines.

Back to the project

The ETI-1515 has been designed to be a good compromise between the crude/economical and complex/ultimate controller. Speed can be set from full rpm on no load (at 'half power') down to less than one-tenth normal. This is lower than you're ever likely to need. On low speeds and without any load there is a tendency for motors to 'hunt' about the set speed, power being applied in detectable jerks. But, even when only a light load is applied, this has the effect of damping the control loop, improving the control and smoothing out the variations.

The torque characteristics of the circuit are excellent, until you approach the 180° limit of the cycle — which is, in any case *way* beyond what you will need in common situations.

A good 'worst case' example is that of making houmous, a particularly thick and pasty (tasty, too!) dip, in a blender. Initially, the mixture is oily, but as the blending proceeds it changes to a *very* glutinous consistency and blenders invariably begin to labour *agonisingly* at this point. With the ETI-1515 in control — no problems!

Construction

Safety is a major consideration in a project such as this. Choosing a box in which to house the components has to be done carefully because the project will be used in a work environment and is likely to encounter more than the usual amount of rough treatment.

I chose a strong, but not brittle, plastic case which comes in two halves, secured by recessed self-tapping screws that set into

The particular case used on the prototype was a 'Unibox', model P/N 140 which measures 135 mm long by 100 mm wide by 38 mm deep.

Shape is unimportant, along with size, just so long as all the components can be fitted with ease and the box is not cumbersomely large. If you choose a box with a metal facia or panel, make sure this is *securely* earthed. If you can, get a box which provides internal posts to which the pc board and SCR mount can be secured with self-tapping screws so that no metal parts attached to these can protrude through the exterior of the case. If you must use a case that doesn't meet this requirement, secure 'the workings' with nylon nuts and bolts. All this is for your own protection.

The potentiometer used was of the conventional type, having a metal case, bushing and shaft. I earthed the pot. case, as shown in the wiring and overlay diagram. If possible, it would be an even better idea to obtain a pot. with a plastic bushing and shaft.

The mains cable *must* be firmly secured with either a clamp-type grommet where it enters the case, or with an ordinary grommet followed by a cable clamp. I used both a clamp-type grommet *and* a cable clamp, for good measure. (That's probably overdoing it, but, please yourself — Ed.)

Best place to start assembling the project is by drilling the few necessary holes in the box. If you are making a direct copy of the prototype, then positioning of the major components is clear from the internal photograph. If you're using a different box then arrange the major components first and determine where you have to drill holes. Don't crowd the parts against one another. Use the blank pc board as a template for marking its mounting hole positions.

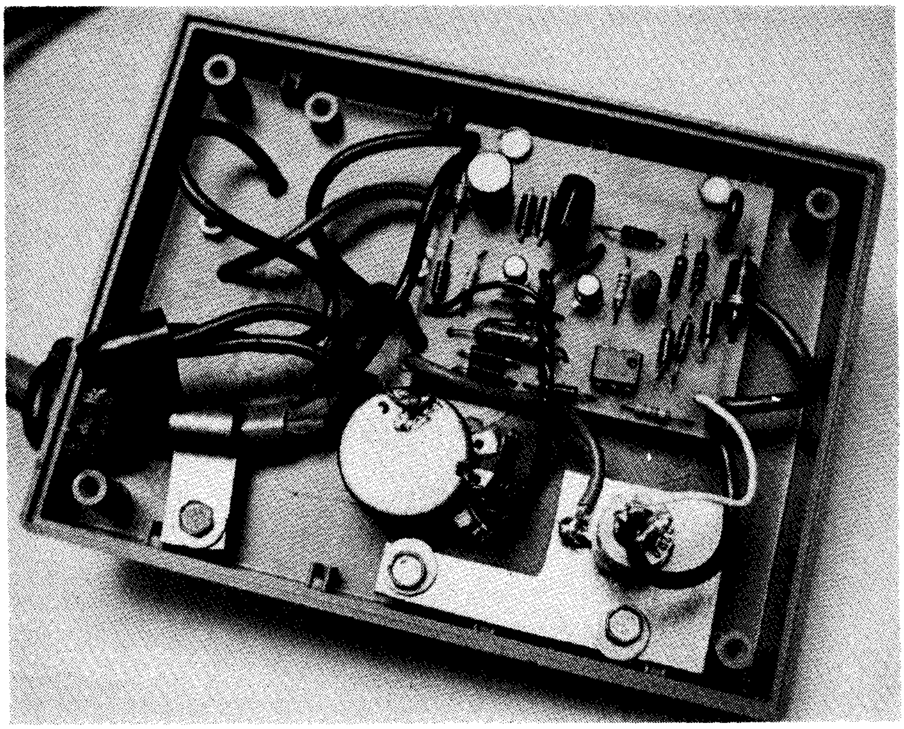
If you're using an SCR type that is not in a stud-mount package, then you'll have to arrange a suitable mount for it. I used a C220D type in a stud-mount, screwing it to a small piece of aluminium which also serves as a heatsink of sorts. SCR dissipation is small, so this heatsink/mount need only be small.

Just bolt the SCR to the heatsink, without any insulator, and use some thermal compound to improve thermal contact between the body of the device and the heatsink. REMEMBER — the heatsink will be at MAINS POTENTIAL, so make sure when mounting it that no securing bolts protrude through the case or use nylon nuts and bolts.

I mounted the SCR separately to the pc board so that a wide range of SCR types and packages could be readily accommodated, from the stud-mount C220D I used in the prototype to small, 6 A-rated, flange-mount plastic pack devices.

It is difficult to specify a 'load rating' for the project in terms of the SCR's characteristics because of motor surge current characteristics and the range of motor ratings in appliances. A 6 A-rated SCR will happily handle an appliance rated to draw a nominal 2 A under 'normal' load. The C220D used in the prototype will reliably handle an appliance rated at four to five amps, right up to full revs setting under almost-stalled-rotor conditions.

Before attaching the 3-pin panel-mount mains outlet socket to the outside of the case,



Inside. Construction is quite straightforward — but take heed of the safety precautions mentioned in the text! Note that, in use, there may be a slight 'dead band' at either end of the speed control rotation where nothing happens.

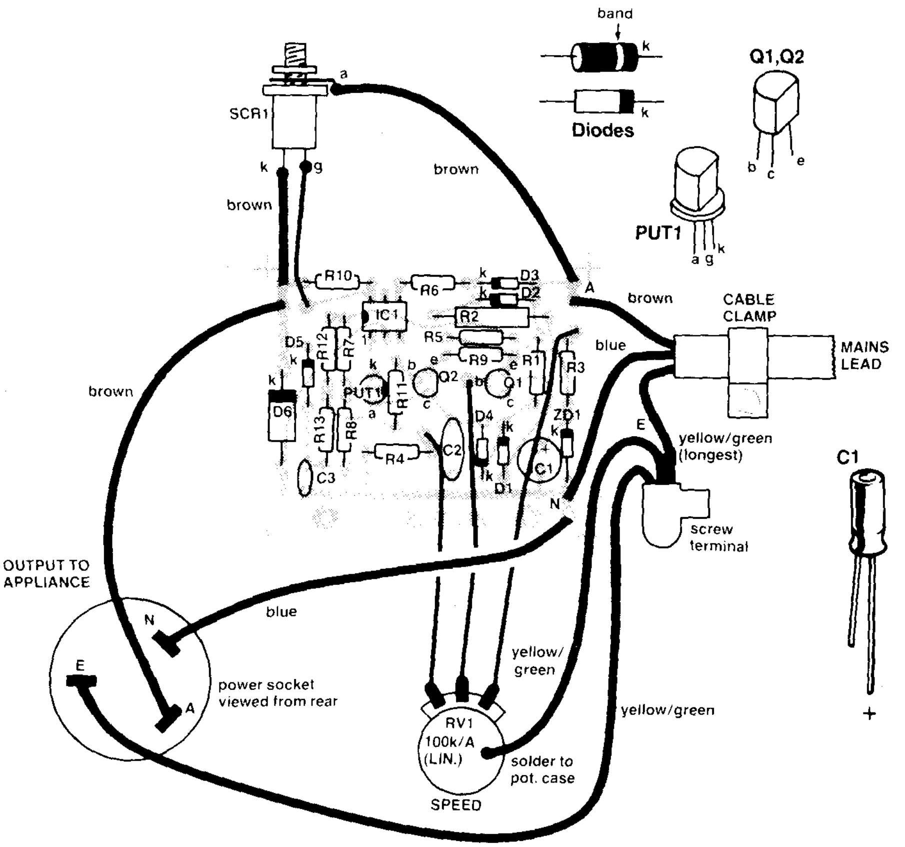
PARTS LIST — ETI-1515

Resistors	all ½W, 5% unless noted
R1	56k
R2	22k, 1 W
R3	82k
R4	27k
R5	33k
R6	1k5
R7	27k
R8	3k3
R9	8k2
R10	1k
R11	10k
R12	100k
R13	15k
RV1	100k/A linear pot.
Capacitors	
C1	22u/35 V RB electro.
C2	100n greencap
C3	10n greencap
Semiconductors	
D1-D5	1N4004, EM410 etc.
D6	1N5404, 1N5606 etc.
IC1	MOC3021 triac opto-isolator
PUT1	2N6027, D13T1 etc
Q1, Q2	BC177, BC557
SCR1	any type, 400 PIV/6A or greater

Miscellaneous

ETI-1515 pc board; case — Unibox P/N 140 (135 x 100 x 38 mm) or similar size to suit; 3-pin panel-mount mains socket; mains cable and plug; small scrap of aluminium, self-tapping screws; screw terminal block; etc.

Price estimate
$20 — $24



Overlay and wiring diagram. Follow this to assemble the pc board and wiring up of the external components. The printed circuit board artwork is on page 102.

Note. If you find your speed potentiometer has a considerable 'dead band' at the 'top' (towards full speed) end, this indicates your drill has lower back-emf than that designed for. The cure is to increase R3. If all the speed control is crowded over about 60° of rotation, increase R3 to 330k. If you get 90° or 100° of rotation for zero to full speed, change R3 to 220k or 180k, etc. You may need to increase R4 from 27k to 56k or 68k, also. DISCONNECT THE UNIT FROM THE MAINS BEFORE MAKING ANY MODIFICATIONS.

attach *colour-coded* wires to its terminals and thread these through the holes drilled for them in the case. Take care that you get the active (A), neutral (N) and earth (E) wires correct. Use wire from a short length of stipped-down mains flex.

When attaching the mains cable, cut back the sheath so as to expose some 150 mm of the three wires to provide connections later. Make sure the cable is very firmly secured.

Mount the potentiometer using nuts on *both sides* of the case panel and lock the bushing tight so that there's no possibility of the pot. body coming loose and being rotated when the knob is turned.

Assemble the pc board next, according to the overlay diagram. You'll find it easier to solder the diodes in place first, followed by the resistors, capacitors and the rest of the semiconductors. As usual, watch the orientation of all the semiconductors and the electrolytic capacitor (C1).

Having done that, *check it*. Make an especially careful examination of the soldering as diagnosis of problems will be dangerous and/or difficult later because the board operates 'live'. In other words, if you are going to make only one project work first time this year, make it this one.

Attach the three wires that go to the potentiometer. Better colour-code or mark these in some way to avoid confusion and wiring errors. Make sure they're long enough. Ordinary hookup wire will do for these. An ordinary piece of hookup wire can also be used for the lead to the SCR gate. The leads to the SCR anode and cathode carry mains potential and load current and should be wired using mains-rated wire. Get it from some stripped-down mains flex, like before.

Now wire up the mains input cable and the mains outlet socket to the pc board, then *check it.*

Note that the earth wire on the mains input cable should be longer than the active and neutral wires. Should the mains cable come adrift, the earth wire would then be the last to break.

The try out

When you're satisfied the project is correctly together it's time for a try-out. Just plug in your drill, blender or whatever into the outlet socket, set the speed pot. a bit up from minimum, plug the controller into the mains and switch on. See that the appliance's motor rotates at some low speed. Advance the speed control and see that the motor speed increases, as expected. If nothing's happening at this stage, switch off, unplug everything and go over your wiring (this assumes you *know* the appliance works).

If that works, then try applying a load with the motor set at some convenient speed and see that the controller maintains the motor speed. If not, you've got troubles on the pc board and you'd better unplug everything and go over it.

If you are using the unit with an unusual motor, where the inertia of the armature may be greatly different to that expected by this circuit, you can vary the gain of the feedback amplifier by simply changing the value of R9. This can be varied between a minimum of about 150 ohms and a maximum of 22k.

Thus, if the motor hunts excessively (especially at low speed settings), R9 may be increased from the 8k2 value shown, reducing feedback loop gain and restoring stability at a small price in speed constancy. If the reverse is the case, you can acquire tighter regulation by reducing R9 — but check that hunting is kept to a minimum.

Finally, several words of caution are in order. The power bursts which are applied to the motor by the SCR switching and the control system variations with the motor armature running at low speed, applies a lot of stress to the motor's brushes and armature windings, so the controller should not be used in applications where it's not really necessary. Wear from the controller's use is unlikely to significantly shorten the life of an appliance, but it is never good practice to strain a mechanical device unnecessarily.

In addition, many appliance motors, particularly drills, employ a small cooling fan on the armature. The cooling effect of the fan is reduced and extended periods of operation at low speeds should thus be avoided. ●

Radioteletype-computer decoder

This simple project allows you to hook up your MicroBee to a receiver and print radioteletype messages on the VDU screen. A simple bit of software does the decoding. The project can also be adapted for use on other Z80-based systems.

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IF YOU OWN a MicroBee, or other Z80-based computer, you can now set up your own teletype listening post. But you can forget the old bucket of bolts teleprinter, the computer now serves that purpose.

Besides the computer itself, you'll need to write in the 'Bees parallel input port, build the new ETI-733 RTTY decoder and have a decent HF receiver capable of copying single sideband signals.

You may remember, back in August 1979, a project called the ETI-730 Radioteletype Converter. That design worked well then and it works well now. It's still quite current and it appears that hundreds of them have been built around Australia. This new design is meant to complement the ETI-730. Under rough reception conditions, the '730 will win every time, but under reasonable signal conditions the ETI-733 comes out ahead in ease of operation, speed range and general usefulness. Perhaps a head-to-head comparison is in order; see Table 1.

The performance differences are due to completely different design concepts. The purpose of a decoder is to turn a varying audio tone into a dc voltage proportional to the incoming tone frequency. In the case of radioteletype there are only two frequencies representing two dc levels . . . 'mark' and 'space'. The tones are separated by an amount known as the 'shift' (see the accompanying panel).

The ETI-730 uses filters to recover the two tones from whatever other rubbish may be coming out of the receiver. It compares the level of the tones and whichever one is stronger gets the nod from the logic circuitry. There is another filter in the logic area that discourages transitions faster than 50 per second. The effect of all this is to allow the copy of signals that are sometimes even too weak to hear.

	ETI-730	ETI-733
Ease of Construction	Moderate	Easy
Cost	Moderate	Cheap
Ease of Operation	Fiddly	Easy
Weak Signal Performance	Good	Fair
With Interfering Signal	Good	Poor
High Data Speeds	Poor	Good
Decode Analogue Signals	No	Yes

Table 1. Comparing the '730 and '733.

Gasp! . . . a PLL!

The ETI-733 is based on a phase-locked loop. This will bring screams of anguish from RTTY purists. They'll tell you phase-locked loops are no damn good on HF signals and only marginally useful on VHF. I must admit I experimented with an NE565 PLL chip during the design of the ETI-730 converter and I found results were hopeless. But now, some three years later, from the depths of a CMOS logic data book, comes the *4046 Micropower Phase-locked Loop*, and it goes like a ripper. Why this one should work when the 565 didn't, I can't explain, but work it certainly does.

You've probably heard of PLLs as part of frequency synthesisers. When the cost of crystals shot out of sight, PLLs became a necessity in multi-channel transceivers. The basic PLL has a voltage controlled oscillator and a phase comparator. The signal to be decoded is fed into the phase comparator along with the output of the VCO. The comparator generates an error voltage that's fed back to the VCO (that's the loop part). The VCO then adjusts its frequency to match that of the incoming signal. So the VCO output is a cleaned-up carbon copy of the signal from the receiver and the error voltage is our recovered data signal.

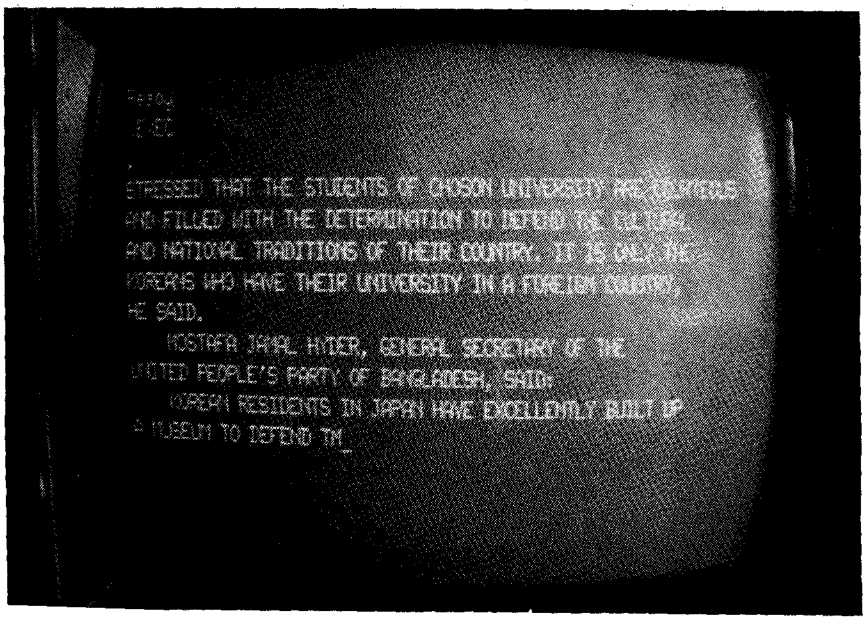
When everything is hanging on and the VCO is following the input signal, the PLL is said to be 'in lock'. If the incoming signal is too high or too low in frequency, beyond the range where the VCO can be pushed to match it, the whole procedure falls apart and the PLL 'loses lock'.

One of the advantages of the PLL system is that you can put a low pass filter in the line between the phase comparator and the VCO which effectively averages out higher frequency noise on the incoming signal, allowing the loop to remain in lock. A disadvantage is that it will always lock onto the strongest signal within its locking range, even if it's not the signal you're trying to receive.

The 4046 chip has a few extra goodies. One is a second phase comparator working on a complicated 'digital' principle. There's also a source-follower to buffer the loop signal for output, and even an on-chip zener diode for power supply regulation. In this design we've ignored the zener diode and the digital phase comparator. The latter was thoroughly tested but the 'normal' phase comparator worked better in this application.

Overall design

Circuit constants were found strictly by the eclectic empiricist method (i.e: trial and error!). After starting with the data book's suggested values, a tape of rather scruffy off-air RTTY signals was played into the



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STRESSED THAT THE STUDENTS OF CHOSON UNIVERSITY ARE [illegible]
AND FILLED WITH THE DETERMINATION TO DEFEND THE CULTURAL
AND NATIONAL TRADITIONS OF THEIR COUNTRY. IT IS ONLY THE
KOREANS WHO HAVE THEIR UNIVERSITY IN A FOREIGN COUNTRY,
HE SAID.
    MOSTAFA JAMAL HYDER, GENERAL SECRETARY OF THE
UNITED PEOPLE'S PARTY OF BANGLADESH, SAID:
    KOREAN RESIDENTS IN JAPAN HAVE EXCELLENTLY BUILT UP
A MUSEUM TO DEFEND TH_
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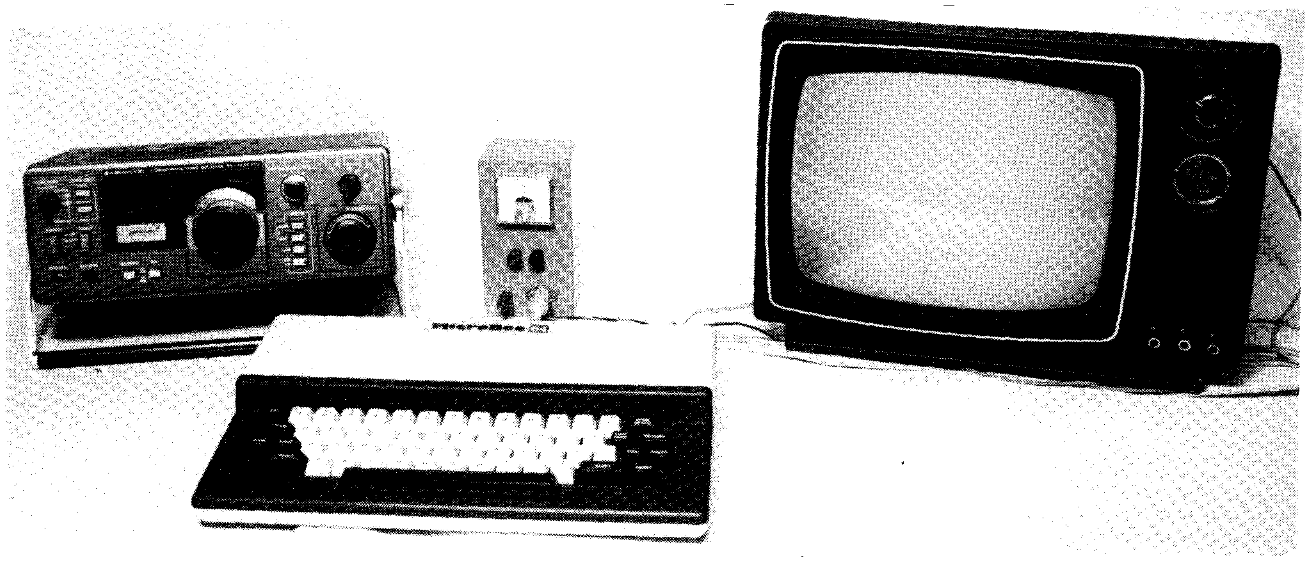


Your 'glass teletype' terminal. Add a general coverage receiver, the '733 decoder and a MicroBee (or similar Z80 system)!

PLL and the results sent to the mechanical teleprinter. A count of errors was made, a circuit constant changed, and then the same bit of tape was played again to see if the errors got worse or better.

It was a slow business but I managed to zero in on what appears to be the best performing circuit.

The lock range is from 1400 to 3400 Hz, in the higher part of the receiver's audio passband, and the loop filter constants are such that signals beyond 300 baud can be recovered.

As well as the PLL chip, the ETI-733 decoder uses an LM324 quad op-amp for input and output conditioning. One section raises the audio level from the 'recorder' output of the receiver to a level more suitable for the PLL.

The PLL output goes to two inputs of another op-amp used as a comparator. One input gets the PLL signal, lightly filtered. The other also gets the PLL signal, but this time via a very long time constant filter to produce an average of the PLL swings. This line is buffered by an op-amp, which also drives a tuning meter.

The arrangement causes the comparator to make a firm decision as to whether a mark or a space is being received, while allowing the signal to drift all around within the PLL's lock range. Shift selection is no longer required . . . anything that crosses the comparator threshold is considered valid, and signals down to 170 Hz shift work nicely.

Since the PLL lock range is 2000 Hz, a lot of receiver drift is tolerable before copy is lost.

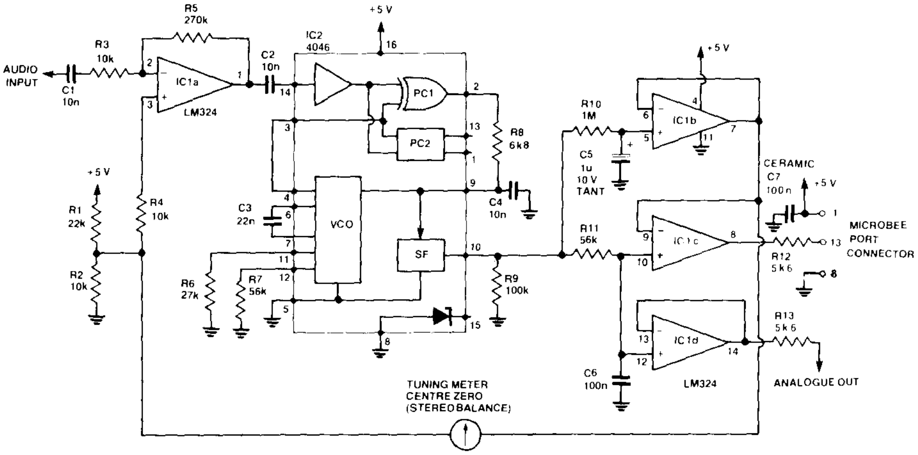
There is one disadvantage with this averaging system . . . teletype signals sent slowly, by hand, will be hard to copy. This is because the signal is spending most of its time on 'mark' and the comparator will drift toward mark, losing its centre reference. But that's of little worry, most interesting signals are sent by machine anyway.

Another op-amp enables a feature that has been examined by oscilloscope, but not properly tried yet . . . an analogue output. The PLL can track anything, not just two discrete audio tones. This opens the door for signals using frequency modulation, such as satellite pictures, weather maps, any facsimile-type signals — and these abound on the HF bands.

When one of these is being received an oscilloscope shows a nice video signal from the analogue output. A signal restricted to peak black and peak white appears on the digital output. A bit of playing around with a computer should result in a method of displaying analogue material on the screen. That's certainly one to work on.

Once the digital signal is available at the decoder's output, you can send it one of two places: to a teleprinter, or to a computer. For the teletype option you can pinch the loop driver circuit from the ETI-730 article.

(See ETI, August '79, page 43. Delete the two resistors, R29 and R30, and LED1 from the emitter circuit of Q2 and take the emitter directly to earth. Feed the PLL decoder output to the base of Q2 via R27.) ▶



HOW IT WORKS — ETI-733

The heart of the decoder is IC2, a 4046 'micropower phase-locked loop' IC. The incoming signal from the receiver consists of two audio tones — one to represent the 'mark' signal, the other to represent the 'space' signal. The 4046 converts these to a two-level digital signal, which is filtered, then buffered and sent to the computer.

IC1a and associated components forms an ac amplifier with a rolloff below 1.5 kHz (i.e: high pass) and a passband gain of about 27. Resistors R1 and R2 form a voltage divider providing a reference level for IC1a of about 1.6 V.

The amplified signal from IC1a drives the signal input of the PLL, IC2, via capacitor C2, which enables the self-biasing input amplifier of IC2 to work with weak signals.

The PLL phase capacitor, PC1, output is filtered by R8 and C4 to obtain an error signal for the PLL's VCO which should oscillate near the incoming frequency present at any particular time. The VCO frequency is 'pulled' according to the actual mark and space frequencies of the incoming RTTY signal.

The free-running frequency of the VCO is about 2.4 kHz, set by C3 and R6. The lock range of the VCO is determined by R6/R7 and is about 1.4 — 3.4 kHz.

The error signal out of PC1 of IC2 is buffered and appears at pin 10 of the PLL. A low pass filter, formed by R10, C5 and IC1b, removes the fast-changing data components of the error signal, leaving a nominally-dc component at the output of IC1b.

The PLL error signal is also fed to IC1c via another low pass filter formed by R11 and C6. IC1c is connected as a comparator with a reference signal on its inverting input set by the nominal dc level from the output of IC1b. This comparator 'extracts' the data from the error signal. This scheme relies on the input not containing long periods of only one input tone, which is usually true.

The tuning meter connects between the 1.6 V reference provided by R1/R2 and the output of IC1b. This indicates when the receiver is producing audio tones shifting within the PLL lock range. When correctly tuned, the current through the meter is zero, hence the necessity of a centre-zero meter.

The data low pass filter, R11/C6, has a roll-off around 30 Hz, which ensures clean data out. However, some experimentation can be carried out with different data rate signals. You can vary C6, decreasing its value for high data rates, settling on a value which gives best results.

Software

The program that follows was written for the MicroBee, but since it's in machine code it should work on just about any Z80-based machine with only minor modifications to some addresses. Here's how it works:

The aforementioned in/out port is first set up in what's called the 'control' mode . . . you specify some bits as inputs and others as outputs, and no 'handshaking' signals are required. In this case I've called all the bits inputs, although only bit 0 is used to bring in the teletype signals decoded by the ETI-733.

A teletype signal is made up of a start pulse, five data pulses, and an extra-long stop pulse (start and stop refer to shaft rotation that takes place in a mechanical teleprinter). Refer to Figure 1, below. A pulse, in the case of 50 bauds, is 20 ms long.

The program first looks for a start pulse which unleashes the following series of events: Bit 3 of an 8-bit register (register C in the Z80) is set high. Thirty milliseconds later the transmitting teletype should be in the centre of its first data pulse . . . this is read and pushed into the right end of the C register. Everything already in C is shoved to the left to make room. Twenty milliseconds later comes the next data pulse, this is loaded into C and everything else shifts along. After five data pulses the bit originally set in C falls out the left hand end, telling the program that a character is finished. Register C now contains, in its first five bits, a binary number between 0 and 31.

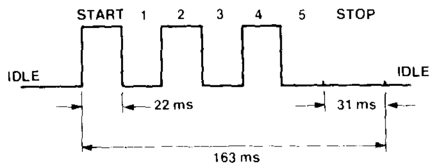
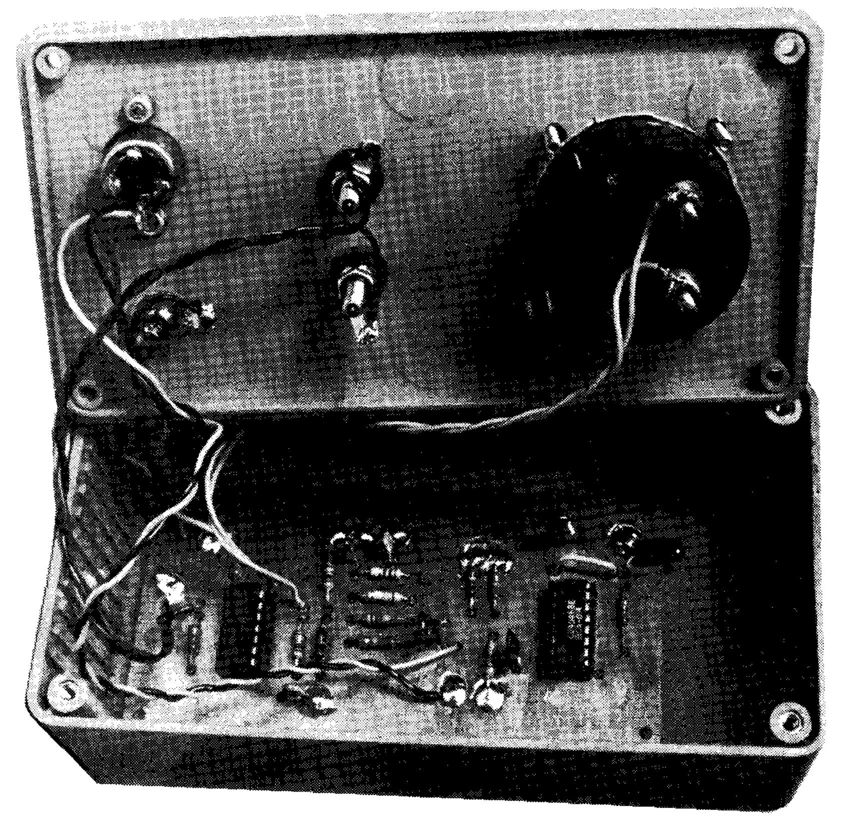


Figure 1. How the teletype signal is made up. For 45.45 baud speed standard, the first five pulses are 22 ms long, followed by a 31 ms 'stop' pulse giving 163 ms per character, while a 50 baud system uses 20 ms pulses with a 30 ms 'stop' pulse, giving 130 ms per character.

In the next part of the program the character in C is inspected to see if it's a figures or letters shift. If so, a flag (register E), is set accordingly. Now register pair HL is set to point to a table of ASCII characters. The number in C is doubled and then added to HL, making HL point to a pair of table entries. Which entry of the pair gets selected depends on flag E which, if zero, gets even numbered entries (letters characters). If E is one, HL selects odd numbered entries (figures and punctuations).

The ASCII character eventually selected is loaded into register B and then sent off to the MicroBee's VDU routine, where it's displayed on the screen. The program then goes back to looking for another start pulse for the next character.

If your MicroBee is a BASIC-only version, getting the program into it could be a problem. Although there are only 139 bytes in the program, they can only be entered in memory by 'poke' statements, but then there's no easy way to save the program on tape. If you want to try it anyhow, first convert the hexadecimal values in the 'code' column, eight bits at a time, to decimal. Then poke them into the hex addresses in the 'ADDR' column.



Then again, you could take the easy way out. For the sum of 12 miserable dollars, sent to the author, you will receive a postpaid cassette tape which can be loaded into your MicroBee with the usual 'load' command.

This tape contains an extended 'bells and whistles' version of the RTTY program, with such goodies as baud rates from 45.45 to 300, selectable while the program is running, selectable page or tape display mode, and signal inversion at the touch of a key.

Construction

All the 'electronic' bits go on a pc board measuring about 120 mm by 60 mm. Only the tuning meter and input/output connectors are mounted separately. As a concession to the 'RF purists' I used a double-sided pc board with a groundplane on the component side of the board. As we're dealing only with audio signals here, you can ignore the groundplane if you so wish. As for sockets for the two IC's — please yourself, they have no effect on circuit operation.

Assembly of the pc board is straightforward. Probably the easiest way to tackle it is to solder the resistors in place first, followed by the capacitors. Watch the orientation of the 1 uF tantalum, C5. Install IC1 and then IC2. Note that the latter is a CMOS type and the usual static and soldering precautions should be taken. Note that there is one link on the board — near one end of IC2.

Finally, attach the wires that go to the meter and input/output terminals. If using a double-sided pc board, some components are soldered on the top *and* bottom side of the board — denoted by a • on the overlay.

You can mount the decoder in a box if you wish: any suitably-sized jiffy box will do nicely. The meter and input/output terminals can be mounted on the box's lid. Nothing's critical, so exact construction details are left up to you as individual requirements will undoubtedly vary a great deal.

Hooking it up

Figure 2 shows the general idea of how the

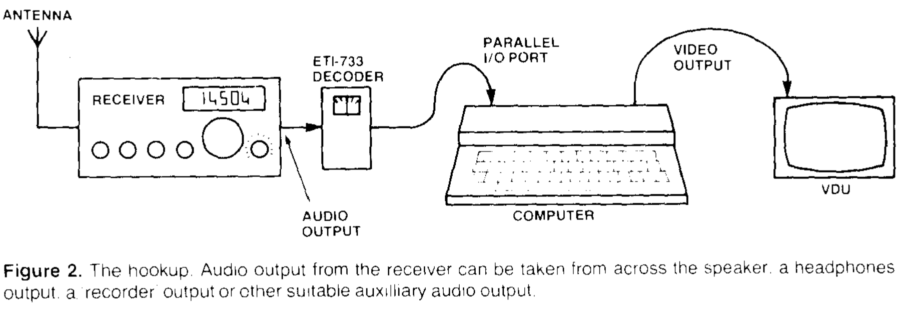


Figure 2. The hookup. Audio output from the receiver can be taken from across the speaker, a headphones output, a 'recorder' output or other suitable auxilliary audio output.

PARTS LIST — ETI-733

Resistors .... all ½W, 5%

R1	22k
R2, 3, 4	10k
R5	270k
R6	27k
R7, R11	56k
R8	6k8
R9	100k
R10	1M
R12, R13	5k6

Capacitors

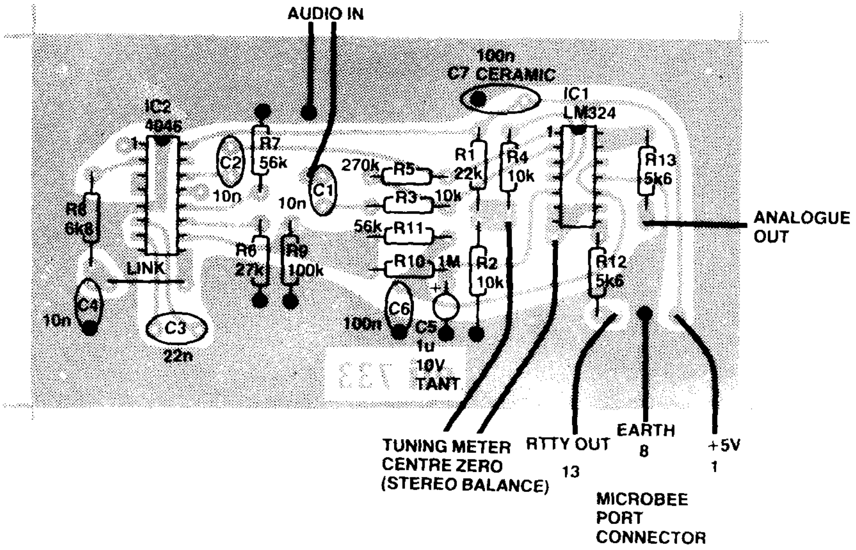
C1, 2, 4	10n greencaps
C3	22n greencap
C5	1u/10 V tant.
C6	100n greencap
C7	100n ceramic bypass

Semiconductors

IC1	LM324
IC2	4046

Miscellaneous
ETI-733 pc board; M1 — centre-zero tuning meter; DB15 plug; wire, etc.

Price estimate $16 — $20



The printed circuit board artwork is on page 102.

decoder fits in the system. The audio output from the receiver can be taken directly across the speaker, from any auxiliary audio output or a headphones output. Less than one volt of audio will provide adequate drive to the decoder.

To use a MicroBee computer you'll first have to arrange a parallel input/output port. If this was not supplied with your computer, you'll have to install it yourself. All that's required is the 15-pin ('DB15S') socket which you can buy from your local electronics store and wire it in yourself (very carefully). While it wires straight in, note that bit 0 of the port comes out on pin 13, not pin 11, as the pc board overlay or kit construction manual indicates. The output of the ETI-733 decoder connects to bit 0 and it gets power supply from the computer via pin 8 of the port connector.

All you need now is some means of converting the decoder output to characters on the VDU screen. That's where we need a little software.

For other Z80-based computers, we'll have to leave the details to you as individual systems vary. Have a close look at your system's technical manual.

On the air

To test your new decoder, here are some frequencies to try:

11 030 kHz	AXM, coded weather info, 50 bauds
13 779 kHz	Voice of America News, 75 bauds
14 700 kHz	Christchurch to McMurdo, 75 bauds
16 100 kHz	Chinese News Agency, 50 bauds

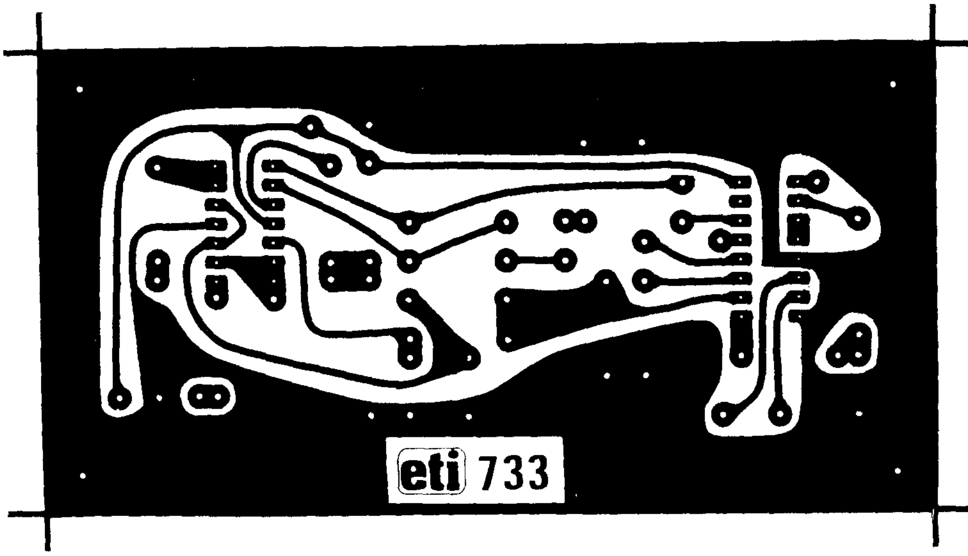
With the receiver set for the upper sideband mode, tune for centre reading on the decoder meter. If the signal is garbled, try it on the other sideband. An off-centre meter reading under no-signal conditions is normal. Happy spying. ●

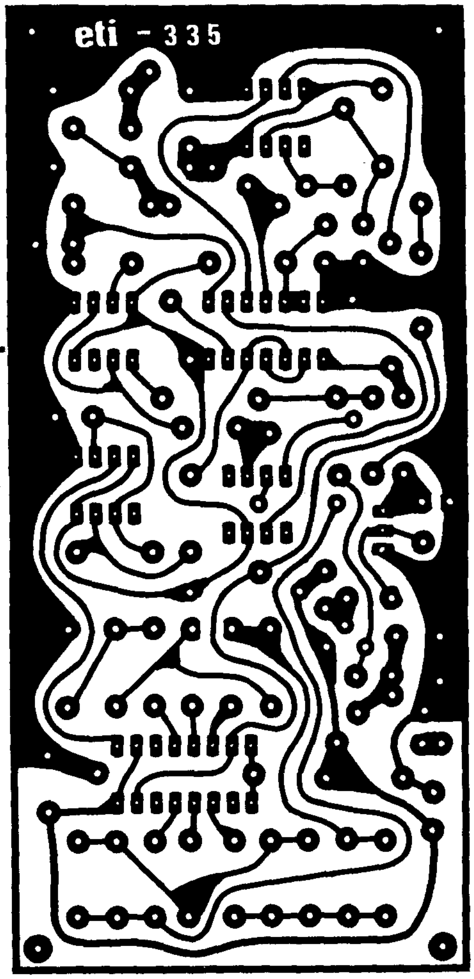
SOFTWARE

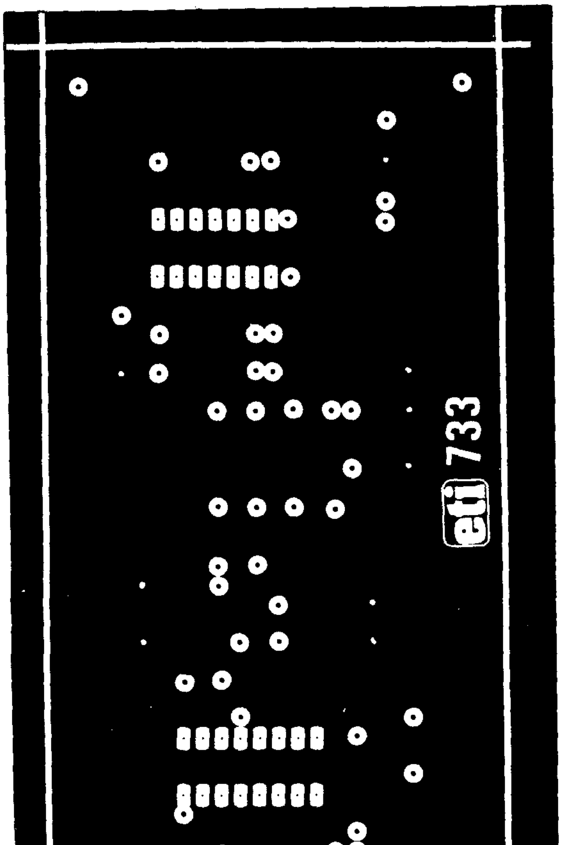
```
ADDR   CODE    LINE   LABEL  MNEM   OPERAND

               00100 ;RTTY RECEPTION PROGRAM FOR 50 BAUDS
               00110 ;(SHORT VERSION) by Tom Moffat
               00120
0400           00130        DEFR   16       ;ASSUME HEX NUMBERS
0400           00140        ORG    0400
               00150
               00160 ;5-bit serial input routine, through PIO BIT 0
               00170
0400 3ECF      00180        LD     A,0CFH   ;SET PIO FOR "CONTROL"
0402 D301      00190        OUT    (1),A
0404 3EFF      00200        LD     A,0FFH   ;SET ALL BITS "INPUT"
0406 D301      00210        OUT    (1),A
0408 DB00      00220 INPT   IN     A,(0)    ;LOOK FOR START BIT
040A CB47      00230        BIT    0,A
040C 20FA      00240        JR     NZ,INPT
040E 0E08      00250        LD     C,8      ;SET UP COUNTER BIT
0410 CD4204    00260        CALL   DELAY1   ;START BIT IS LOW, ...
0413 CD3F04    00270        CALL   DELAY2   ;DELAY TO CENTRE OF DB-1
0416 DB00      00280 LOOP   IN     A,(0)    ;BRING IN DATA BIT
0418 CB3F      00290        SRL    A        ;SHIFT DATA INTO CARRY
041A CB11      00300        RL     C        ;SHIFT CARRY INTO C
041C CD3F04    00310        CALL   DELAY2   ;ONE BIT TIME
041F 30F5      00320        JR     NC,LOOP  ;RPT TILL COUNTER BIT OUT
               00330
               00340 ;Conversion to ASCII, BAUDOT character in C.
               00350
0421 214C04    00360        LD     HL,TABLE
0424 0600      00370        LD     B,0
0426 1600      00380        LD     D,0
0428 79        00390        LD     A,C
0429 FE1B      00400        CP     1BH      ;IS BAUDOT CODE <FIGS> ?
042B 2002      00410        JR     NZ,$+4   ;SKIP NEXT IF NOT FIGS
042D 1E01      00420        LD     E,1      ;SET FLAG "FIGS"
042F FE1F      00430        CP     1FH      ;IS BAUDOT CODE <LTRS> ?
0431 2002      00440        JR     NZ,$+4   ;SKIP NEXT IF NOT LTRS
0433 1E00      00450        LD     E,0      ;SET FLAG "LTRS"
0435 CB21      00460        SLA    C        ;LET C = C * 2
0437 19        00470        ADD    HL,DE    ;ADD FLAG TO POINTER
0438 09        00480        ADD    HL,BC    ;ADD CHR TO POINTER
0439 46        00490        LD     B,(HL)   ;ASCII CHAR INTO B
043A CD0C80    00500        CALL   800CH    ;OUTPUT CHAR TO VDU.
043D 18C9      00510        JR     INPT     ;GO BACK TO START
               00520
               00530 ;Time delay subroutine
               00540
043F CD4204    00550 DELAY2 CALL   DELAY1
```

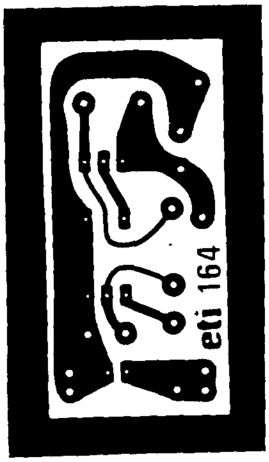
```
0442 3E78      00560 DELAY1 LO     A,120D   ;DO 120 TIMES FOR 50 BAUD
0444 060B      00570 LOOP1  LD     B,0BH
0446 10FE      00580        DJNZ   $        ;JUMP TO YOURSELF IF NZ.
0448 3D        00590        DEC    A
0449 20F9      00600        JR     NZ,LOOP1
044B C9        00610        RET
               00620
               00630 ;ASCII lookup table arranged by BAUDOT value
               00640
044C 0505      00650 TABLE  DEFW   0505     ;(BLANK)
044E 5435      00660        DEFW   3554     ;T 5
0450 0D0D      00670        DEFW   0D0DH    ;(CR)
ADDR   CODE    LINE   LABEL  MNEM   OPERAND

0452 4F39      00680        DEFW   394FH    ;O 9
0454 2020      00690        DEFW   2020     ;(SPACE)
0456 4800      00700        DEFW   0048     ;H (STOP)
0458 4E2C      00710        DEFW   2C4EH    ;N ,
045A 4D2E      00720        DEFW   2E4DH    ;M .
045C 0A0A      00730        DEFW   0A0AH    ;(LF)
045E 4C29      00740        DEFW   294CH    ;L )
0460 5234      00750        DEFW   3452     ;R 4
0462 4724      00760        DEFW   2447     ;G $
0464 4938      00770        DEFW   3849     ;I 8
0466 5030      00780        DEFW   3050     ;P 0
0468 433A      00790        DEFW   3A43     ;C :
046A 563D      00800        DEFW   3D56     ;V =
046C 4533      00810        DEFW   3345     ;E 3
046E 5A2B      00820        DEFW   2B5AH    ;Z +
0470 4400      00830        DEFW   0044     ;D
0472 423F      00840        DEFW   3F42     ;B ?
0474 5327      00850        DEFW   2753     ;S '
0476 5936      00860        DEFW   3659     ;Y 6
0478 4625      00870        DEFW   2546     ;F %
047A 582F      00880        DEFW   2F58     ;X /
047C 412D      00890        DEFW   2D41     ;A -
047E 5732      00900        DEFW   3257     ;W 2
0480 4A87      00910        DEFW   874AH    ;J (BELL)
0482 0404      00920        DEFW   0404     ;(FIGS)
0484 5537      00930        DEFW   3755     ;U 7
0486 5131      00940        DEFW   3151     ;Q 1
0488 4B28      00950        DEFW   284BH    ;K (
048A 0B0B      00960        DEFW   0B0BH    ;(LTRS)
0000           00970        END
00000 Total errors

LOOP1    0444    TABLE   044C    LOOP    0416    DELAY2  043F
DELAY1   0442    INPT    0408
```

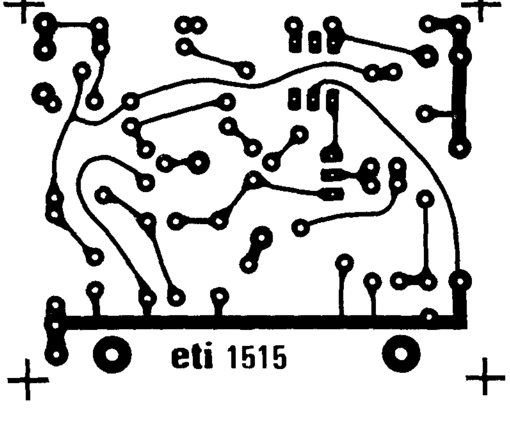
PCBs







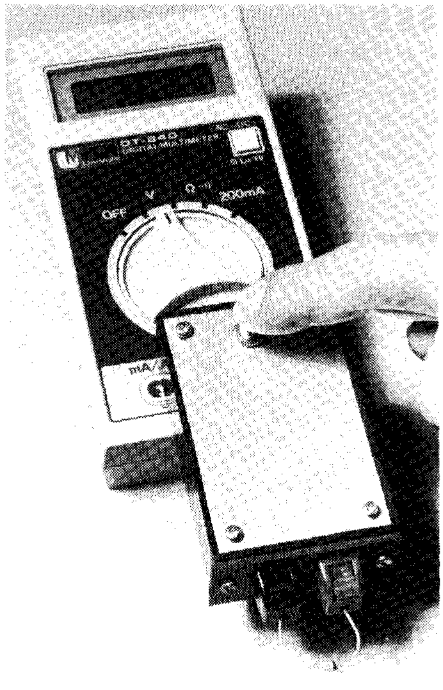




Zener diode tester plugs into your multimeter

Geoff Nicholls

This handy little adjunct for your multimeter allows you to read out the actual zener voltage of any zener diode up to 60 volts and will also test LEDs!



Push-to-read. The tester is housed in a 'zippy' box with banana plugs protruding from the rear spaced to suit the multimeter input sockets spacing.

EVER DUG INTO a tray of components looking for a zener diode only to find that the markings have worn off? Even a brand new zener is usually marked with a code number giving little indication of the thing you want to know — the actual zener voltage rating. This simple tester will save you thumbing through the data books looking for a 1N4XXX, and allows easy identification of those unmarked diodes.

Most multimeters have a diode check position, but few can test LEDs, let alone zeners. This handy little adjunct for your multimeter allows you to test zeners up to about 60 volts, and can drive enough current through a LED to light it (and give you a reading of its forward voltage drop).

The tester simply plugs into your multimeter (a digital meter is ideal) and gives a direct reading of zener voltage. The circuit uses an inverter to provide a current-limited output of up to 70 volts dc from a nine volt battery. Table 1 shows the output characteristics of the prototype.

The leads on diodes are designated *anode* and *cathode*, the latter being marked by a band. When connected to the tester with the cathode to the black or negative terminal, the multimeter will indicate the diode forward voltage. For a silicon diode this will be about 650 mV while a germanium diode will read around 300 mV. Zener diodes are normally operated in reverse bias and are therefore tested with the cathode (banded end) connected to the red or positive terminal so that the zener voltage is displayed on the meter.

Zener characteristics

The zener voltage rating of a diode is only a nominal figure and should be considered with other parameters when designing circuitry. The first thing to realise is that the zener voltage is rounded to the *nearest preferred value*. Secondly, the voltage rating is dependent on the current passing through the diode. The diode manufacturers usually quote zener voltages at a current of 5 mA for voltages up to 30 volts and at 2 mA above this.

Low voltage zeners will not develop their nominal voltage until the current reaches a few milliamperes. As the diode current is increased the voltage drop will also increase, representing a dynamic resistance which varies from tens of ohms for zeners between six and ten volts, to hundreds of ohms outside these limits.

Lastly, the zener exhibits a temperature sensitivity that varies with zener voltage as shown in Figure 2. A detailed explanation of the temperature characteristic may be found in any solid state physics textbook, the essential features being a negative temperature coefficient associated with true zener breakdown below six volts and a positive temperature coefficient associated with avalanche breakdown above six volts.

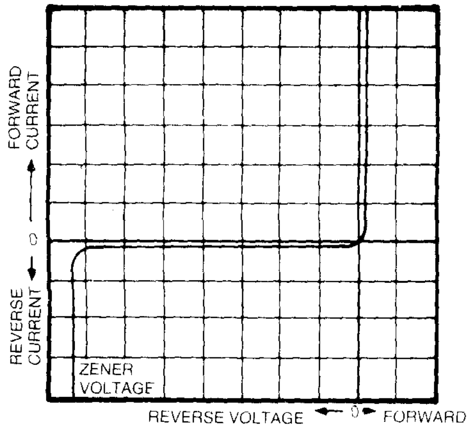


Figure 1. The fundamental characteristics of a zener diode. Little reverse current flows until a certain voltage — the zener voltage — is reached. This voltage is almost constant.

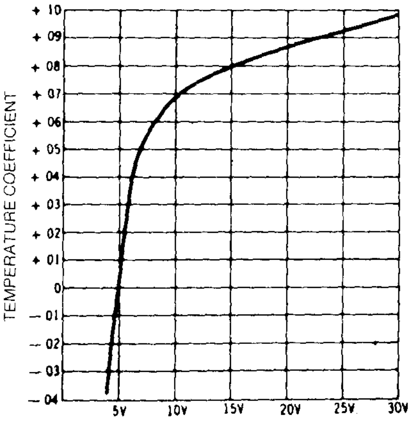


Figure 2. Temperature characteristics of zener diodes — depends on the zener voltage value.

It is possible to combine zener diodes with opposing temperature coefficients in order to obtain a near temperature-independent reference, or to use a normal diode (with a negative coefficient) and a zener with the same result.

For further information on practical zener usage, refer to *ETI Circuit Techniques, Vol. 1*, pages 136 to 141.

Construction

I built the zener tester into a plastic zippy box with metal lid measuring about 30 x 50 x 80 mm. This is the smallest common low cost box that will accommodate the electronics and battery.

The pushbutton switch is mounted centrally in the lid about 10 mm from one end with the two banana plugs in the box underneath the switch. The spring terminals mount on the other end of the box, as shown in the photographs. You may wish to vary construction to suit the components on hand, but check ▶

TRANSFORMER NOTES

The transformer used in this zener tester is a 'transistor audio transformer'. Two separate types were tested, with virtually equivalent results.

The Dick Smith M-0216, described in the catalogue as being 'primary 1k ohm CT/secondary 8 ohm' was the one used in designing the circuit (CT means 'centre tapped'). Although described as having a ferrite core, the several we purchased had iron cores.

Many component suppliers stock this transformer, or an equivalent type. For example, Altronics call it an 'output transformer', catalogue number M 0216; Electronic Agencies have a '1k CT/8 ohm' mini transformer listed as cat. no. ME4012.

Just for safety's sake, in case the 1k CT/8 ohm transformers may not be available at some time or another, we tried a 500 ohm CT/8 ohm type from Altronics, cat. no. M 0226. Many other suppliers stock a transformer like this, too. As results were virtually equivalent, we can safely say transformers of this type may be used for T1 also. Connections were found to be the same as the M-0216.

Note that it may be physically larger, necessitating mounting R1 on the copper side of the board.

that the bits all fit together before chopping up your box.

The banana plugs are mounted at a spacing of 0.75", or about 19 mm, which allows the tester to plug straight into a standard multimeter with 'GR' inputs.

To mount the plugs, first remove the plastic handles and cut them down to 20 mm so they can be fitted inside the box. Solder about 100 mm of insulated wire to each plug and feed the end through the holes in the box. Grab each plug with pliers and push them through the holes from the bottom. Now slip the handles over the wires and tighten up the plugs.

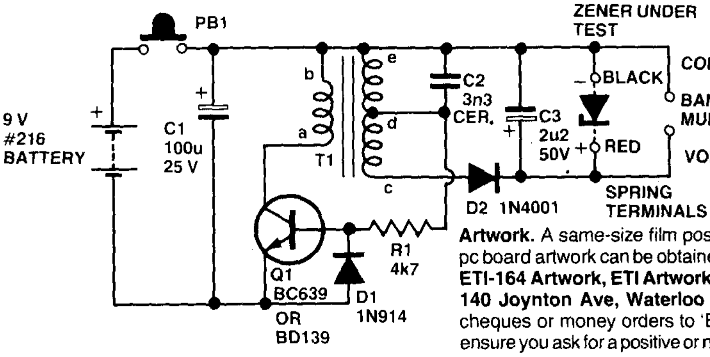
If all that seems too much, you may want to simply bring a couple of wires out to the multimeter with the banana plugs soldered to the ends.

The spring terminals I used had mounting holes about 45 mm apart which allowed screws to tap into the plastic pillars in the corners of the box. You may also mount the terminals on the long side of the box. In any case, a couple of holes will be necessary under the spring terminals to allow the solder lugs to pass through.

The pc board is straightforward to assemble, watch the orientation of the electrolytic capacitors, the two diodes (note: D1 is the smaller) and the transistor. There are several types of transformer available and some may *require* R1 to be mounted on the copper side of the board in order to fit properly. The pc board may slot into a groove inside the box, or simply lay alongside the battery as in our prototype. ●

TABLE 1 Performance of prototype.

OUTPUT VOLTAGE volts	OUTPUT CURRENT mA	BATTERY DRAIN mA
0	5	140
5	8	160
15	9	190
24	9	190
48	5	160
60	1.5	130
72	0	120



Artwork. A same-size film positive or negative of the pc board artwork can be obtained for $1 post paid from **ETI-164 Artwork, ETI Artwork Sales, ETI Magazine, 140 Joynton Ave, Waterloo NSW 2017.** Make out cheques or money orders to 'ETI Artwork Sales' and ensure you ask for a positive or negative as you require.

HOW IT WORKS — ETI-164

The operation of apparently simple inverter circuits is usually exceedingly complex, so the following is a simplified explanation!

After PB1 is closed, current flows through terminals 'e' and 'd' of the transformer (and C2) to the base of Q1 via R1. Q1 starts to conduct and causes current flow through transformer terminals 'b' and 'a' (the primary winding) which causes the magnetic field to build up in the transformer. This field increases the base current to Q1 because of the phasing of the windings.

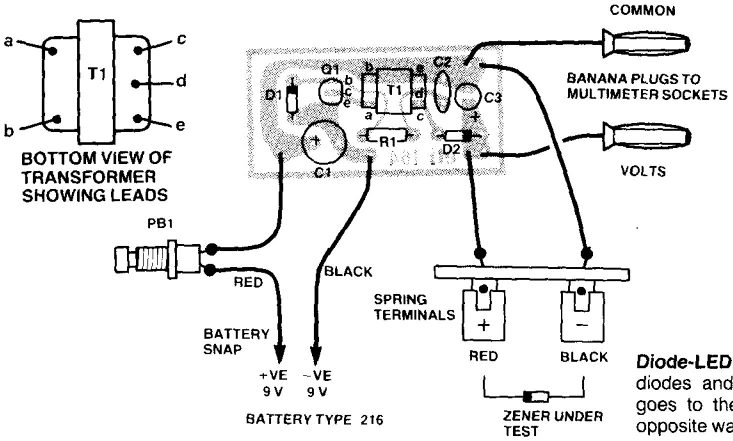
The magnetic field increases until the transformer core saturates, when the transistor base current reverses, turning the transistor off.

Diode D1 protects the base-emitter junction against excessive reverse bias voltage.

The energy in the transformer's magnetic field is dissipated via several mechanisms, one being to charge C3 via D2.

The whole cycle repeats at a rate of a few kilohertz.

Capacitor C1 provides a low impedance source to ac signals and improves operation with a battery supply.



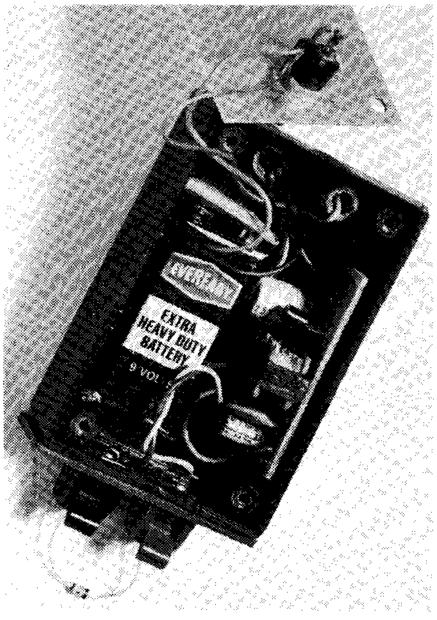
Diode-LED test. When testing diodes and LEDs, the **anode** goes to the **red** terminal, the opposite way to zeners.

PARTS LIST — ETI-164

Resistor	¼W, 5%
R1	4k7
Capacitors	
C1	100u/25 V (or 16 V) RB electro.
C2	3n3 ceramic
C3	2u2/50 V RB electro. (see text).
Semiconductors	
D1	1N914
D2	EM401, 1N4001, EM402, 1N4002, etc.
Q1	BC639 or BD139
Miscellaneous	
PB1	momentary action pushbutton
T1	transistor audio transformer, '1k CT to 8 ohm', D.S.E. M-0216 or similar (see text).

ETI-164 pc board; UB5 zippy box (28 x 54 x 83 mm); spring terminals; wire etc.

Price estimate $8 — $9



Inside story. Internal view of the zener tester. Note the cut-down banana plug handles at the top of the box.

Project 734

The 'Phony Patch' — a landline interface for your ham rig

Be ready for 'phone patch when it comes. In the meantime, you can practice operating your rig over the house intercom, or whatever.

The phone patch committee*

SPECIFICATIONS — ETI-734

SENSITIVITY	
Rx-to-line (at 1 kHz)	
level pot. mid-position	**3.0 V for 0.77 V (0 dBm) in line**
level pot. maximum	**1.5 V for 0.77 V (0 dBm) in line**
Line-to-Tx (at 1 kHz)	
level pot. mid-position	**0.77 V (0 dBm) in line gives 0.5 V out**
level pot. maximum	**0.77 V (0 dBm) in line gives 1.3 V out**
CROSSTALK	
Rx output to Tx input	
level pots mid-position (dependant on level settings; decreases with higher settings)	**26 dB with 0 dBm on line**

*** All voltages RMS; line terminated in 600 ohms**

ONE OF the more positive aspects of the CB 'boom' was that it paved the way for 'third party traffic' in both the citizens bands and (later) the amateur bands.

Third party traffic means that an amateur or CB operator is allowed to relay messages, via his equipment, to another amateur or CB operator for someone else (i.e: neither of the operators).

This in itself was a 'breakthrough', but didn't go quite far enough. For it still meant that the message had to be actually re-broadcast by the operator.

The ridiculous part was that, if the message was being relayed from Australia to, say, the USA, the American amateur could connect his transceiver directly to his phone, call the party to whom the message is directed — and sit back!

This is because amateurs in the United States have long had access to 'phone patches', which were fully legal to connect to the telephone network. In Australia there has been no method of connecting a transceiver to a telephone line.

The current situation is this: the Department of Communication permits third party 'phone patch' operation for amateurs, but to connect a phone patch device to Telecom lines would breach Telecom regulations — with the risk of having your service disconnected plus prosecution for effecting a 'non-permitted' attachment.

In fact, not only are phone patches not permitted, but there are no standards laid down to which equipment can be made. Certain safety standards for equipment in general are all that can be relied on.

The recent report of the Davidson Inquiry into telecommunications foreshadows that Telecom is, or shortly will be, taking a much more enlightened attitude to attachments to their phone lines. Witness the recent decision by Telecom to allow 'user connected' phone devices to be plugged in to Telecom lines (for the first time — until now any item, even permitted, had to be 'installed' by Telecom).

In light of the changing attitude of Telecom, we set about designing an interface which could, when allowed, connect transceivers to Telecom lines. In the meantime, there are a large number of private installations, intercoms, links etc. which could still make use of such a device.

In the absence of any technical specifications, the interface was made to meet all of Telecom's safety standards. It was also designed to meet the audio level requirements of other equipment.

The interface is equipped with its own monitor speaker so it can be used as a direct link between the transmitter and line. Obviously, normal transceiver operating practice must be followed as the transceiver will only operate in simplex mode.

However, the interface can make use of the

▶

** This project was designed, developed and written up by a group of radio amateurs interested in promoting 'phone patch in Australia. They modestly wish to remain anonymous.*

transceiver's VOX, if available, for 'hands free' operation.

It is anticipated that a large number of amateur operators, and maybe even CB operators, will build the interface, ready for the time when such devices are 'legalised'. And it appears that this is not too far away!

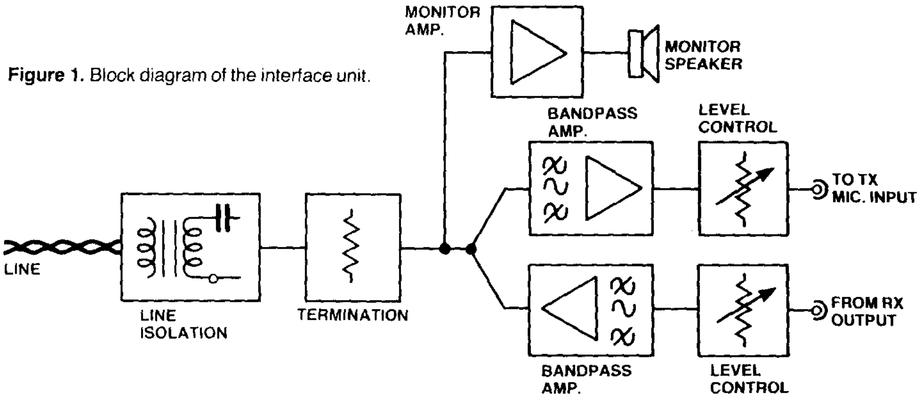


Figure 1. Block diagram of the interface unit.

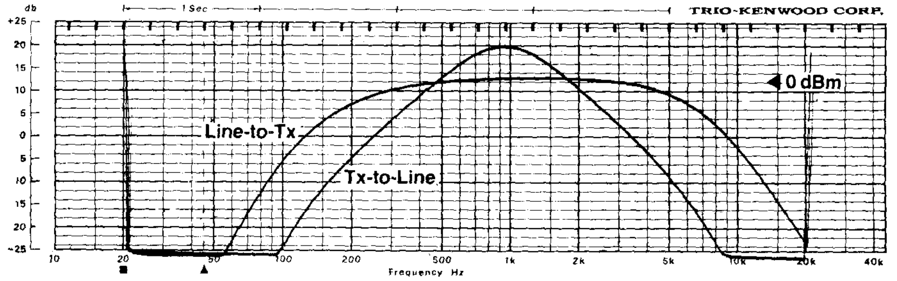


Figure 2. Response curves of the 'Rx-to-line' and 'Line-to-Tx' stages of the interface. (Measured on the prototype using ETI's Trio SE-3000 acoustic test set.)

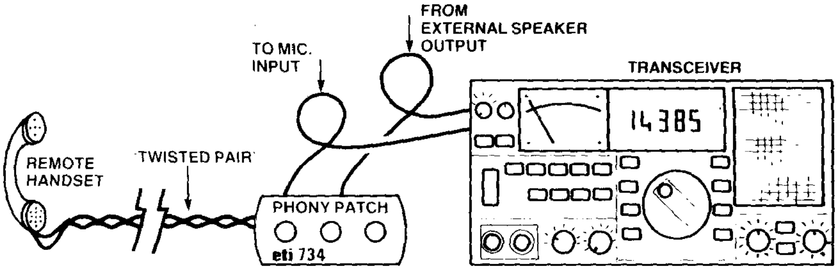
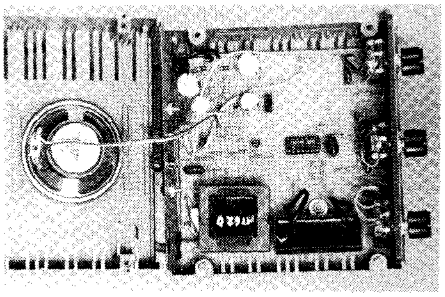


Figure 3. General arrangement of how the ETI-734 interface unit is hooked up.



Inside story. General internal view of the project.

Design

A block diagram of the interface is shown in Figure 1. The object is to convert a 'four wire' communications path — a pair for the receiver output and a pair for the transmitter input — to a 'two wire' link.

For safety's sake, and to take into account the later likelihood of the unit requiring approval for attachment to Telecom lines, the interface is isolated from the line by a special transformer and a high voltage, high reliability capacitor. This is terminated in a resistance of a value that provides a close match to the general line impedance of about 600 ohms.

A bidirectional amplifier system is attached to this to pass audio from the line to the transmitter mic. input and from the receiver output to the line. Each of these amplifiers has a bandpass response. Figure 2 shows the two response curves.

The response from receiver output to the line shows a narrow bandwidth with steep rolloff above and below the speech midband frequency of 1 kHz. The −6 dB bandwidth is from about 500 Hz to 1.7 kHz, rolling off at about 12 dB per octave below 500 Hz and at about 15 dB per octave above 1.7 kHz. This is perfectly adequate for speech, and in fact, provides a measure of improvement with noisy signals as well as attenuating noise and heterodynes that may be passed down the line.

The response from the line to the transmitter mic. input is considerably broader, the −6 dB bandwidth running from about 200 Hz to 6 kHz. Rolloff below 200 Hz is about 12 dB per octave, about −15 dB per octave above 6 kHz. Why is it different? Well, many modern transceivers incorporate speech filtering and bandwidth shaping to improve the effectiveness and clarity of the signal. Any filter in the mic. line may adversely affect the performance of a transceiver's own speech filter. But, any extraneous noise (hum, clicks-pops, etc) that may be on the line should not be passed to the transceiver, either. Hence the line-to-Tx filter response was rolled off above and below the usual speech band limits of 3 kHz and 300 Hz, respectively.

The 'Rx output' is intended to come from the transceiver's external speaker output or a high level, low impedance auxilliary output. Most modern transceivers have an audio power output of around two to three watts. Under normal use, average output power into the speaker is perhaps 0.5 W, which is about 2 V into an eight ohm load. Hence, this amplifier was designed to deal with signals from about 1.5 V RMS (level control at maximum) to produce 0 dBm in the line (0.77 V in 600 ohms).

With the line-to-Tx amplifier, 0 dBm on the line will produce a maximum output of about 1.3 V RMS (level control at maximum), which should be more than adequate to handle the majority of situations.

For local monitoring, a simple amplifier picks audio off at the isolation stage and drives a small loudspeaker in the interface.

Power is derived from an ac plugpack so that mains is not brought into the unit at all — again, for safety's sake.

Construction

All the electronic components, with the exception of the pots, are mounted on a single printed circuit board measuring 113 mm square. This fits nicely inside an ARLEC PC1 plastic case which we used to house the project. This case has a plastic front panel and a metal rear panel. The pc board has four mounting holes at each corner that match the plastic pegs in the bottom half of the ARLEC case so that the board is easily secured with four small self-tapping screws.

The three pots mount on the front panel and all the external 'interfacing' connections exit via the back panel. The transceiver connections are made via two RCA sockets. The line enters via a grommet and is soldered to the appropriate pc board points. A flying lead with a suitable plug attached permits convenient connection to and removal from the line. The ac plugpack adaptor was hard wired direct to the board using figure-8 cable. Some plugpacks come with a flying lead of Figure-8 cable, some have two screw terminals on the plugpack body.

We dressed up the front panel with an aluminium Scotchcal label. The monitor speaker was mounted on the lid, simply glued in place with Silastic. Holes were drilled in the lid over the speaker position, before mounting (it's too hard afterwards!).

Probably the best way to go about constructing the project is to tackle the pc board first. If you're making your own board, give it a thorough check after etching and drilling it. Even if you've purchased a ready-made board or a kit, check the board for missed holes, bridges between tracks (particularly between IC pins) and holes not drilled to the correct size. Make sure the four mounting holes line up with the pegs in the base of the box. Correct any problems and then proceed with mounting the components.

Assemble the resistors, capacitors (except C2) and semiconductors first. If you wish, a socket can be used for IC1. Watch the orientation of the electrolytic capacitors and all the diodes, especially. The orientation of the transistors and IC1 should be clear from the overlay diagram.

Leave the line isolation transformer, T1, and capacitor C2 until last as these are bulky components. We used pc stakes for all the external leads from the board. These should be mounted next. Check everything so far. All OK? Now bolt C2 in place, then mount T1. C2 has flying leads, note, while T1 has been designed for direct pc board mounting.

Now you can attach the flying leads to the pc board stakes around the perimeter of the board. Make sure the leads are long enough to reach their destination, but not too long so that they form a 'rat's nest' inside the box when it's all assembled. Don't attach the line or ac input leads yet.

Now you can tackle the box. Mark out and drill the front and rear panels. The Scotchcal label can be used as a template to mark out the front panel. Drill holes in the box top where the speaker will be positioned, then glue the speaker in place.

The Scotchcal label can now be applied to the front panel. Trim the label to size first. Cut it slightly undersize, the box pieces have an overhanging lip which covers the panel all round the edge. Peel off the backing strip and carefully position one end of the label on the panel. Smooth the Scotchcal onto the panel slowly, then give it a hard rub all over, using a soft cloth, when you've got it in place. Trim off any overhanging bits.

Now mount the potentiometers to the front panel. Position them so that their terminals face upwards; this makes it easier to solder the leads to them. Put grommets in the holes in the rear panel where the line and ac input leads will pass through. Mount the stereo RCA connector strip (or two individual RCA sockets).

Screw the pc board into place in the bottom

AC PLUGPACKS

There are a number of ac plugpacks available that will suit this project.

The prototype was powered by a **Dick Smith Electronics M-9555** ac plugpack which is rated at 12 Vac/500 mA.

The **ARLEC APP.V/79309/60672** is rated to deliver 12.8 Vac no load, 9.3 Vac at 1 A. The project draws about 125 mA (quiescent) and this plugpack will deliver around 12.5 Vac at that load current.

The **Ferguson PPB 8/1000** is rated to deliver 8 Vac at 1 A, and delivers about 11.5 V or so at around 150 mA, so it will suit, as would their **PPB 12/500** (12 V @ 500 mA).

PARTS LIST — ETI-734

Resistors	all ¼W, 5%
R1	82R
R2, R4	150k
R3	15k
R5, R8	1k5
R6, 7, 22, 23	220R
R9, R10	2R2
R11, 14, 17, 20	68k
R12	560R
R13	39k
R15, R18	4k7
R16	1k2
R19	1M5
R21	22k
RV1	22k/C log. pot.
RV2	500R/C log. pot.
RV3	5k/C log. pot.

Capacitors

C1	10n/400 V or 630 V greencap
C2	2u/440 Vac film cap. (see text)
C3	10n greencap
C4, 6, 10	100n greencap
C5	33n greencap
C7	220n greencap
C8, C9	4n7 greencap
C11, C12	330u/25 V RB electro.
C13, C14	1000u/16 V RB electro.

Semiconductors

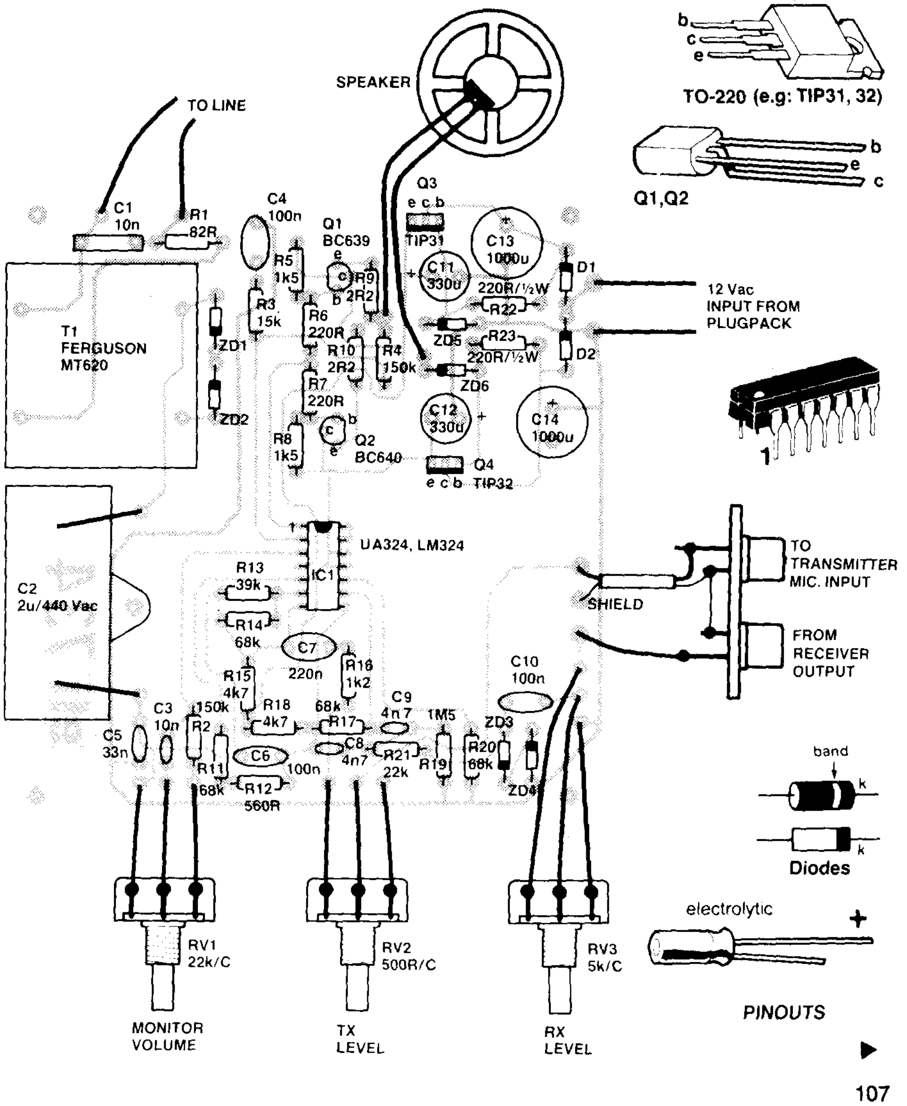
D1, D2	1N4001, 1N4002, EM401, EM402, etc.
IC1	uA324, LM324, etc.
Q1	BC639
Q2	BC640
Q3	TIP31
Q4	TIP32
ZD1, 2, 5, 6	5V6/1 W zeners
ZD3, ZD4	4V7/1 W zeners

Miscellaneous

T1	Ferguson MT620 line isolation transformer

ETI-734 pc board; Arlec PC1 box or similar (plastic, 140 x 130 x 78 mm); 50 mm diameter 8 ohm speaker; Arlec ac plugpack adaptor 9.3 V @ 1 A, or similar; stereo RCA socket strip; one rubber grommet; knobs; Scotchcal front panel; wire, etc.

Price estimate
$55 — $65



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HOW IT WORKS — ETI-734

The overall design of the interface is detailed under design notes in the main text

The line and interface are coupled via T1 which provides isolation to Telecom requirements. Further isolation is provided by the coupling capacitor, C2. Capacitor C1 and resistor R1 attenuate transients on the line. Two back-to-back zener diodes, ZD1 and ZD2, clip any signals with amplitudes above about 6 V peak.

The interface side of T1 is terminated by R12, which provides a close match to the 600 ohm line impedance. The junction of R12-C6-C8-R17-etc is a 'virtual earth' point.

Signals going in the line-to-Tx direction are coupled into IC1b via R11. The output of IC1b is coupled to the level control via C7 and R16. Capacitor C5 provides high frequency rolloff, as its impedance decreases with increasing frequency, while C6 provides low frequency rolloff as its impedance increases with decreasing frequency and the feedback ratio increases (R14 divided by the impedance of R13-C6). Frequency response is shown in Figure 2. The characteristics of T1 also affect the high frequency rolloff. IC1b has a mid-band gain of a little under two.

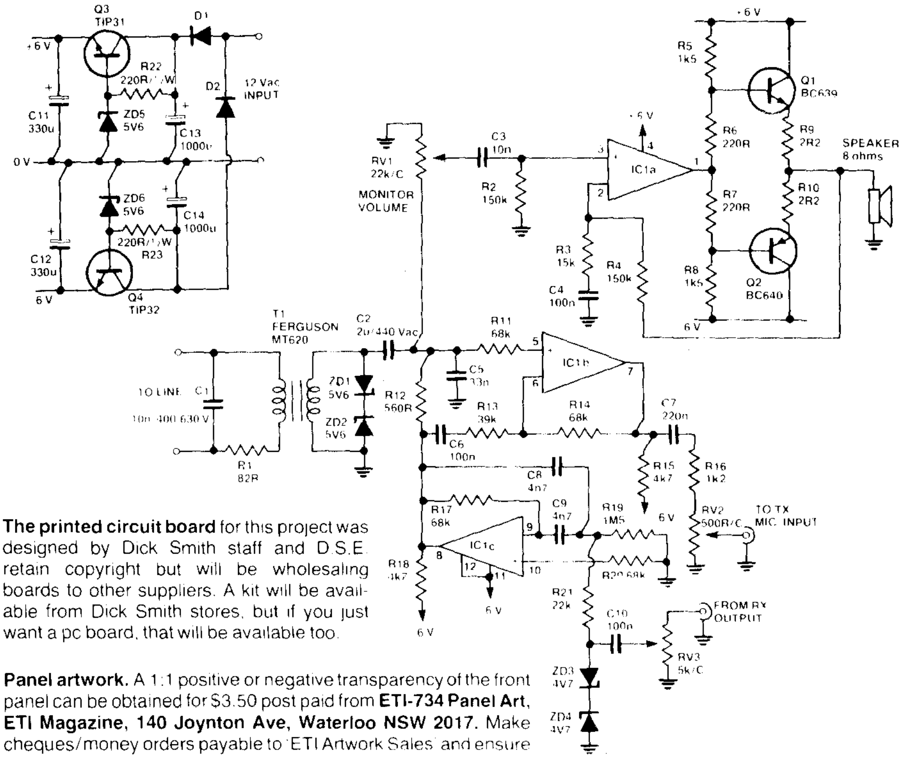
Signals going in the Rx-to-line direction pass via the level control RV3, then via C10, R21 and C9 to the input of IC1c. Two zener diodes, ZD3 and ZD4, clip any signals with amplitudes exceeding about 5 V peak. IC1c is a filter having loss, not gain, as the receiver output level will generally be higher than the required 0 dBm line level. Capacitor C8 provides high frequency rolloff as it shunts the feedback, reducing IC1c's gain with increasing frequency. Capacitor C9 provides low frequency rolloff as its impedance increases with decreasing frequency. The frequency response of this stage is shown in Figure 2.

Now, it is obvious that the output of the Rx-to-line stage is coupled to the line-to-Tx stage. Why then, doesn't the output of the receiver appear at the Tx mic. input? Well, R12 ties the inverting and non-inverting inputs of IC1b together, the Tx output looks like a common-mode signal and will not be amplified by IC1b. It's not a 'perfect' arrangement, but the cross-coupling between the Tx output and Tx mic. input is adequately low.

For the purpose of local monitoring, signals appearing at the common coupling point — the junction of C2 and R12 — are 'picked off' by RV1, the monitor volume control. Signals are coupled to the input of IC1a via C3/R2. The output of IC1a drives a simple class B amplifier comprised of Q1,Q2 and associated resistors, which drives a small eight ohm loudspeaker. Negative feedback is provided via R4 to the inverting input of IC1a. This stage has a midband gain of 10. Low frequency rolloff is provided by C4, the impedance of which rises with decreasing frequency, thus increasing the feedback ratio.

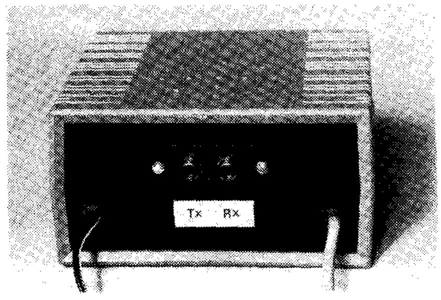
The interface requires positive and negative power rails. An ac plugpack, delivering 12 Vac output, provides power and isolation from the mains for safety. Two halfwave rectifiers, D1 and D2, provide positive and negative dc rails, of about 16 V or so, smoothed by capacitors C13 and C14 respectively. These are each regulated to about 5 V or 6 V using simple zener controlled series pass regulators comprised of Q3,ZD5,R22 and Q4,ZD6,R23. The two zeners are each 5V6, though 6V2 or 6V8 zeners could be used. The supply rails will each be equal to the zener voltages less the b-e drop of the series pass transistors (about 0.6 V). Thus, with 5V6 zeners, the supply rails will be about 5 V each, or with 6V2 zeners, about 5½ V. The actual supply rail voltage is not critical.

Capacitors C11 and C12 provide ac bypassing for the supply rails.



The printed circuit board for this project was designed by Dick Smith staff and D.S.E. retain copyright but will be wholesaling boards to other suppliers. A kit will be available from Dick Smith stores, but if you just want a pc board, that will be available too.

Panel artwork. A 1:1 positive or negative transparency of the front panel can be obtained for $3.50 post paid from **ETI-734 Panel Art, ETI Magazine, 140 Joynton Ave, Waterloo NSW 2017.** Make cheques/money orders payable to 'ETI Artwork Sales' and ensure you ask for a **negative** or **positive.**



In and out. Rear view of the interface showing the ac input line at left, the RCA sockets for connections to the transceiver and the cable to the line at right.

half of the box. Slip the front and rear panels in place and solder the appropriate flying leads to the three pots and the RCA connectors. Solder the speaker leads in place, then pass the line lead and ac input lead through their respective grommets and knot them just inside the box, to prevent strain on the board terminals, if they're pulled, then solder them to their respective pc stakes.

Put the lid on the box and you're ready to test it.

Getting it on the air

Apply power and run a multimeter over the supply rails. These should be within one volt of the specified rail voltage (see the circuit diagram). If you've used 5V6 zeners, for ZD5 and ZD6, the rails will be around 5 V, or a bit over 6 V if you've used 6V8 zeners.

Check the voltage on pin 1 of IC1. This should be less than ±100 mV. The base of Q1 should be about 0.6 V positive, the base of Q2 about 0.6 V negative. See that pin 4 of IC1 is at the positive supply rail and pin 11 at the negative supply rail.

Temporarily hook up a 'phone handset to the line and your transceiver to the RCA connectors. Use a shielded lead to the transmitter mic. input. You won't need a shielded lead between the interface's 'receiver output' socket and the rig's external speaker output as you're dealing with high levels and low impedances. Figure-8 cable is quite OK.

Set the Rx and Tx gain controls to about half way and the monitor gain well down, or you'll get 'howl round' feedback. Set your transceiver VOX controls to where you normally have them, as well as the transmitter mic. gain (if your rig has a mic. gain control).

Turn up the rig's audio gain and listen in the handset for band noise or signals. Set the interface unit's 'Rx output level' control for a comfortable volume in the earpiece.

Talk and the VOX should operate the transceiver. Adjust the interface's 'Tx input level' control and your rig's VOX controls if necessary to get the desired operation.

With the handset located at the end of your twisted pair line, check the overall operation. Adjust the interface monitor level to suit.

Have fun with your 'Phony Patch'!

When the authorities get around to permitting 'phone patch for amateurs, you'll be ready. In the meantime, remember it's an offence to use this unit on the public telephone network. ●

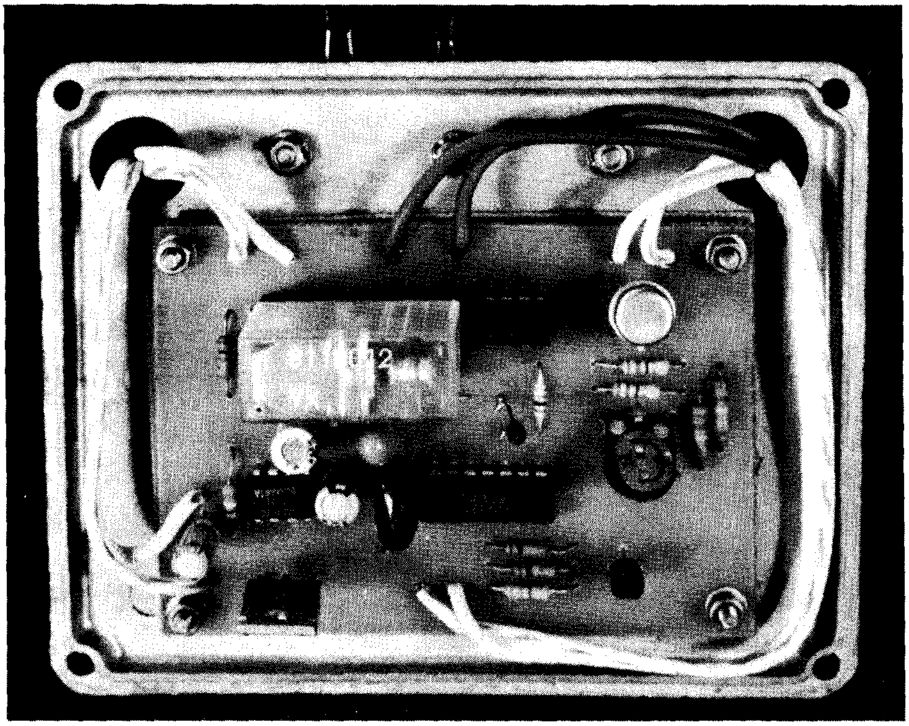
'Current trip' car alarm features exit/entry delay and no false alarms

This car alarm uses the battery earth strap as a sensor to detect when a 'courtesy' light or other electrical load occurs when a thief enters a vehicle. The circuitry is simple and immune from false triggering problems.

Phil Wait

A SIGNIFICANT proportion of cars are stolen at least once in their lifetime. The thieves are generally 'joyriders' who use them for a few hours and then abandon them after vandalising such items as wheels, seats, stereo/radios etc. If you fit a good, reliable alarm you're bound to deter all but the most determined of criminals — who are usually professionals out to 'redo' the car or strip it completely for parts. There's almost nothing that will stop the latter type of thief — alarms, steering locks or any other deterrents notwithstanding.

Early car alarms were electromechanical by nature. They generally had a balanced cantilever or a pendulum with a switch contact attached. Any movement of the vehicle would close the contact and latch on a relay sounding the horn. Simple and effective — but prone to false triggering. They've all but disappeared. Others operated from a series of hood and door switches, but installation often proved a major undertaking.



The completed unit was mounted on the lid of a diecast box with a scrap of blank pc substrate underneath as an insulating spacer. The external leads are passed through two grommeted holes.

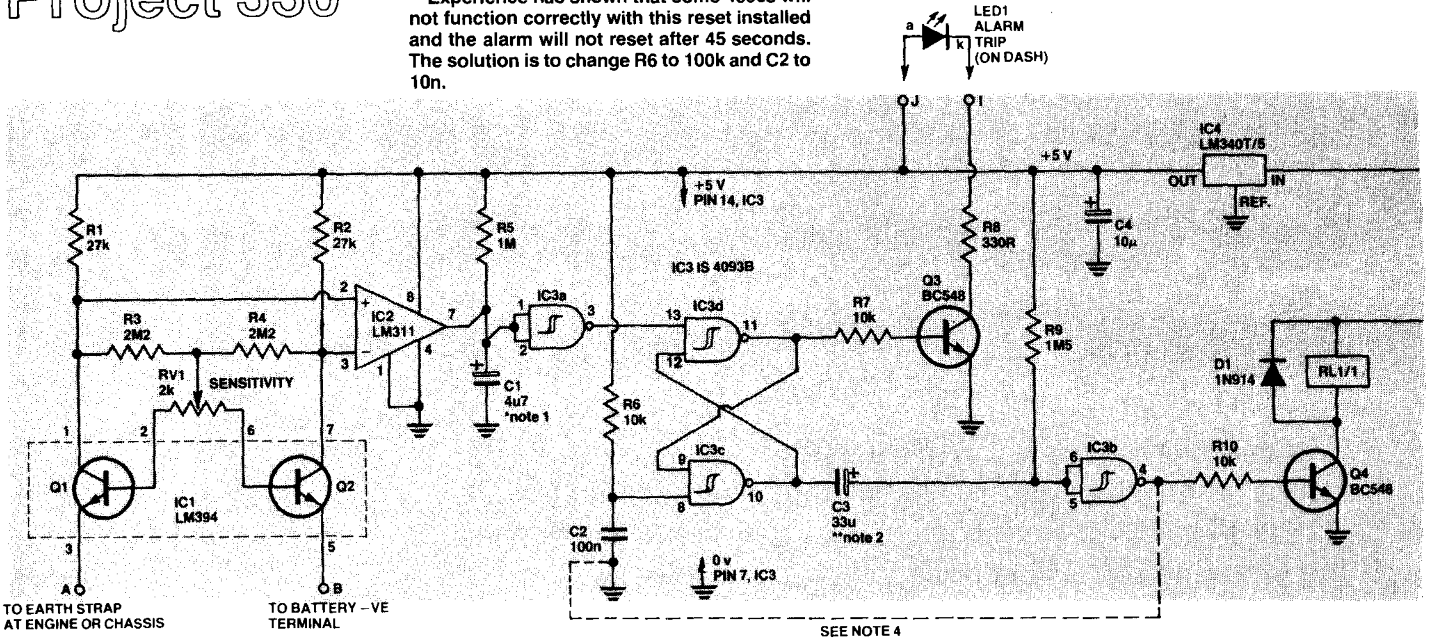
Later alarms became more sophisticated — one type sensed the slight voltage-drop pulse that appears across the vehicle battery's terminals when a load is connected — such as a 'courtesy' light being operated when a door is opened. Reliability often proved a problem with these alarms as they depended on the internal resistance of the battery, which causes the voltage-drop pulse following the connection of a load (the battery terminal voltage drops momentarily and then rises again). Any variation in the terminal clamp resistance produces the same effect — giving rise to false triggering problems.

A cunning variation on this is to detect a voltage drop anywhere in the vehicle's electrical system. We published the design for such an alarm some time back in our book 'Project Electronics' (ETI-084). Whilst a popular project, many constructors reported problems with false triggering. In addition, the alarm did not include entry and exit delay times, which many constructors have requested over the years.

This project employs a similar principle to the ETI-084, but rather a different technique. The battery 'earth' strap has a small, but finite, resistance. Any load on the battery will cause a current to flow through the earth strap (since the vehicle's chassis is used as the return circuit). The current causes a small voltage drop across the earth strap resistance. This is detected and used to trip the alarm. As the 'sensing' input is essentially a very low impedance input, false triggering from magnetic induction or other sources is avoided. Other voltage drop sensing schemes essentially have a medium to high input impedance, hence their susceptibility to false triggering.

Additional measures are incorporated in this project to further reduce the possibilities for false triggering. ▶

Experience has shown that some 4093s will not function correctly with this reset installed and the alarm will not reset after 45 seconds. The solution is to change R6 to 100k and C2 to 10n.



*NOTE 1: Value of C1 sets entry and exit delay times.

**NOTE 2: Value of C3 sets alarm-on time.

***NOTE 3: Value of C5 sets flash and horn pulse rate.

NOTE 4: If you wish the alarm to reset itself after 45 seconds following tripping, lift the 'earthy' end of C2 and connect it to pin 4 of IC3b as shown by the dotted line.

NOTE 5: Capacitors C1, C3 and C5 may be either tantalum types or so-called 'low leakage' electrolytics such as the Elna RBLL, or similar.

HOW IT WORKS — ETI 330

Any load on the electrical circuit of a vehicle will produce a voltage drop across the small, but finite, resistance of the vehicle battery's 'earth' strap. This unit detects that voltage drop and trips an alarm circuit that operates the vehicle's horn. A thief entering the vehicle will inevitably operate a 'courtesy' light or something that draws current, thus tripping the alarm.

The circuit can be divided into five sections: the sense circuit, entry and exit delay circuit, latch circuit, alarm timing circuit and horn pulsing circuit. In addition, a three-terminal regulator provides a 5 V supply to most of the electronics, avoiding problems with false alarms.

THE SENSE CIRCUIT

The current in the earth strap is sensed by a pair of transistors connected in a common base configuration. These two transistors, Q1 and Q2, are encapsulated in an integrated circuit package and are on a single chip of silicon, ensuring that they have very closely matched characteristics. The device is known as an LM394. This device was used in much the same way in our Expanded Scale Vehicle Ammeter, ETI-329, published in the February '81 issue. The base-emitter voltages of each transistor will track within 50 microvolts of each other, a characteristic which is exploited here.

When no current is being drawn from the battery there will be no potential drop across the resistance of the battery earth strap (ignoring the miniscule current drawn by this alarm). Thus, the emitters of each transistor in IC1 will be at the same potential. As the base-emitter voltage of each is virtually identical the collector currents will be identical. Thus initially, the collector-emitter voltage of each will be the same.

When current is drawn from the battery (when a courtesy lamp is operated, for example), a small voltage drop will appear across the battery earth strap. Thus, point A (emitter of Q1) will be raised to a *higher* potential than point B (emitter of Q2). That is, point A will be more positive than point B. The voltage on the collector of Q1 will thus rise (a common base amplifier is a *non-inverting* amplifier).

The voltage difference between the collectors of Q1 and Q2 is monitored by a differential input comparator, IC2 — an LM311. When the voltage on its non-inverting input exceeds the voltage on its inverting input the comparator's output switches high. What happens next we'll get to shortly.

The voltage on the collector of each transistor in IC1 (Q1 and Q2) is initially set by a trimpot, which varies the current fed to each base. This compensates for any slight mismatch between Q1 and Q2 (the dc gain of this circuit is very high) and also acts as a 'sensitivity threshold' control by introducing a preset offset which must be overcome by a certain level of current through the battery earth strap before the alarm will trigger.

ENTRY AND EXIT DELAY

The comparator IC2 has an open collector output requiring an external load resistor — this is R5. When the output of IC2 is low the timing capacitor, C1, is held discharged by IC2's output circuitry. When the alarm is tripped and the output of IC2 goes high C1 starts to charge through R5. After a time determined by the time constant of R5 and C1 the Schmitt gate IC3a toggles over and its output, pin 3, goes low.

LATCH

The Schmitt gates IC3c and IC3d form a latch circuit. On power up, the latch is automatically reset by the time constant of R6 and C2, placing a momentary low on pin 8. The output of IC3c is high and the output of IC3d is low, Q3 is turned off and LED1 is not lit.

When the output of IC3a goes low the latch (IC3d and c) toggles over. The output of IC3d goes high, turning on Q3 and lighting LED1. The output of IC3c goes low at the same time. The latch remains in this state until it is reset when the power is turned off and then on again.

ALARM TIME PERIOD

Before the alarm is triggered the output of IC3c is high and the input of IC3b is held high by R9. As IC3b is wired as an inverter its output is low and Q4 is turned off. When the alarm is triggered the output of IC3c goes low, and since C3 is discharged, the input of IC3b is pulled low, its output goes high and Q4 is switched on, allowing the relay to operate.

The timing capacitor, C3, slowly charges through R9 and, after a period determined by the time constant of C3/R9, IC3b switches over, turning Q4 off again and stopping the horn.

HORN PULSING CIRCUIT

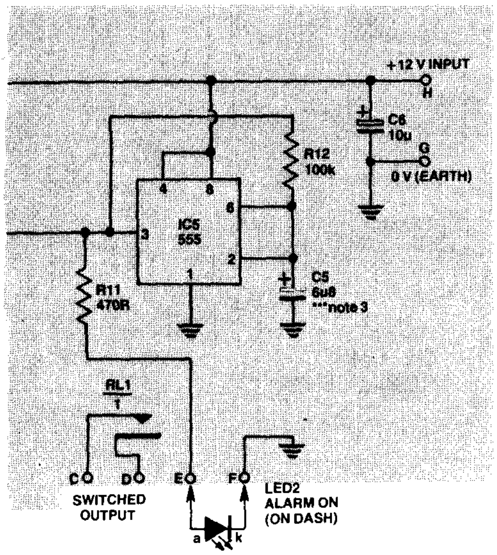
The relay RL1, and therefore the horn, is pulsed on and off about once per second during the horn timing period. IC5 is a 555 timer wired as a free-running oscillator. The frequency of oscillation is determined by the time constant of R12 and C5. As the 555 is capable of driving quite high currents it is connected directly to the relay, which is then switched by Q4. In other words, the 555 pulses the supply to the relay.

The output from the 555 is also used to pulse LED2 (mounted on the dash) as a warning to would-be car thieves and as an indication that the alarm is on.

REGULATOR

A three-terminal regulator, IC4, drops the battery voltage down to 5 V to supply the sense and timing circuits. This protects against false triggering from battery voltage variations and also helps to remove noise from the supply.

Using a Schmitt-triggered input quad NAND gate for IC3 provides further noise immunity and reliable timing due to the precise switching action of its inputs.

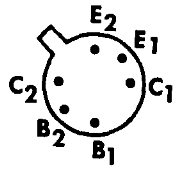


THE LM394 FAMILY AND ALTERNATIVES

There are a number of devices in this monolithic npn dual transistor 'family', each characterised by different tolerance specifications. The LM194 is the mil-spec version which has the tightest specifications and top price. It's also hard to get and its use is not really necessary in this application. The LM394 is available in 'H' and 'C' versions. The LM394H has tighter tolerance specifications than the LM394C and is more expensive. The cheaper LM394C is recommended for use in this project as it is the least expensive member of the family and generally obtainable in good quantities.

Philips manufacture an npn dual transistor family, designated BCY87, BCY88, BCY89, and any of these could be pressed into service in this project, although their V_{be} tolerance specifications are somewhat wider than for the LM394 family. There should be sufficient adjustment available with RV1 to compensate for the wider tolerance in V_{be} offset. The BCY89 is the least expensive, widest tolerance device. Note that the package pinout for the Philips devices is different — see the diagram following.

A further alternative would be to use two transistors from a transistor array IC. The CA3045/46, manufactured by RCA, is a general purpose transistor array IC containing three isolated transistors and one differentially-connected transistor pair. Any two of the isolated transistors may be used. However, this device is encapsulated in a 14-pin DIL package which would have to be glued to the pc board in a suitable place, upside down, and connecting wires run from the appropriate holes in the pc board to the device pins. RV1 should be able to compensate for the wider tolerance in V_{be} offset here too.



BOTTOM VIEW

BCY87/88/89 FAMILY PINOUT

Design

A block diagram of the alarm is shown in Figure 1. The Sense and Trigger circuit detects when the voltage drop across the battery earth strap rises above a predetermined amount. When triggered, this then arms the entry/exit delay. If the alarm does not remain triggered after the delay period nothing further will happen. If it does remain triggered, the delay circuit will trip the Latch and start the Alarm Period Timer. The Alarm Trip Indicator will also light. When the Alarm Period Timer is activated the Relay Driver is also activated. The Relay Pulser will then turn the relay on and off at one-second intervals, pulsing the horn on and off too.

The Relay Pulser circuit operates continuously and flashes a dash-mounted light to indicate that the alarm unit is 'armed'.

After the Alarm Period Timer completes its period, the Relay Driver is turned off and the horn will cease pulsing on and off at one-second intervals. Car alarms are required by law to turn off within ten minutes of being triggered, but can automatically re-arm.

If someone attempts to steal your car, trips the alarm and then abandons the attempt, the Alarm Trip Indicator will remain on, telling you that the alarm was tripped during your absence.

Construction

Our prototype was constructed on a printed circuit board, the artwork for which is reproduced elsewhere in this article. While this is not absolutely necessary — the project could be constructed on matrix board — a pc board does reduce the possibility of wiring errors, which have to be sorted out when you first power up the project.

There is no particular order for assembling the components to the pc board but it is usually easier to solder the resistors and capacitors in place first. Take care with the orientation of the tantalum and electrolytic capacitors. Follow with the semiconductors. Again, watch orientation of these components. The relay should be mounted last of all.

The completed pc board can be mounted in any convenient case — we housed ours in a diecast box measuring 120 x 40 x 95 mm. A diecast box was chosen because it can be effectively sealed against the ingress of dirt, moisture and other undesirable substances.

We mounted the pc board on the underside of the diecast box's lid and fitted a 10-way terminal block on the outside of the lid for all the external connections. Leads from the pc board to the 10-way terminal block are passed through grommetted holes. These were later sealed with Silastic.

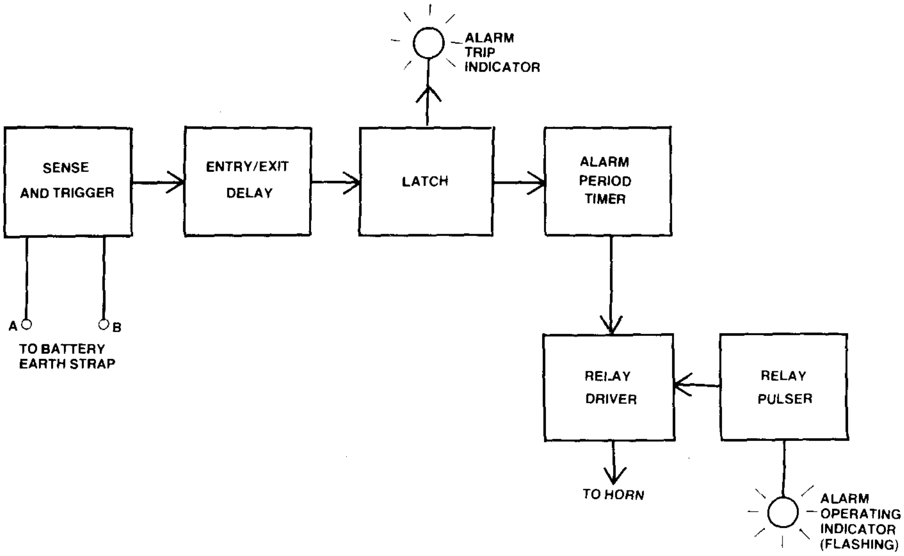
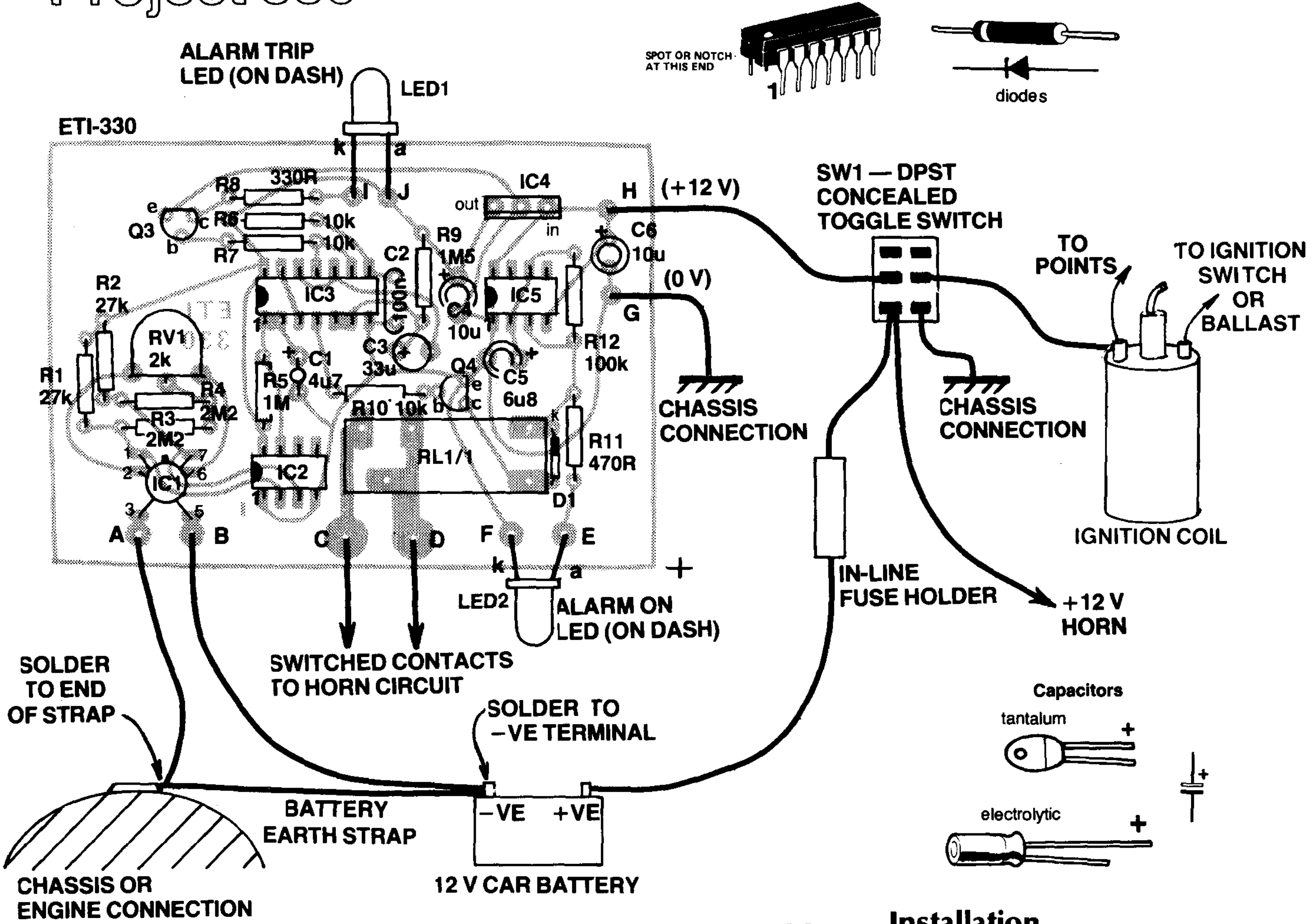
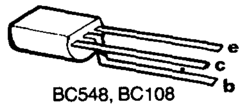
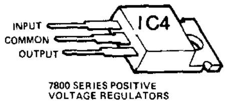


Figure 1. **Block diagram of the ETI-330 car alarm showing the basic functional blocks of the circuit.**







PARTS LIST — ETI 330

Resistors .... all ½ W, 5%

R1, R2	27k
R3, R4	2M2
R5	1M
R6, R7, R10	10k
R8	330R
R9	1M5
R11	470R
R12	100k
RV1	2k min. trimpot

Capacitors

C1	4u7/16 V tantalum or RBLL electro. (See text)
C2	100n greencap
C3	33u/16 V tantalum or RBLL electro. (See text)
C4, C6	10u/16 V electro.
C5	6u8/16 V tantalum or RBLL electro. (See text)

Semiconductors

D1	1N914 or 1N4148
LED1, 2	TIL220R or similar (see text).
Q3, Q4	BC548, BC108 or similar
IC1	LM394 (see text)
IC2	LM311N
IC3	4093B
IC4	LM340T/5 or 7805
IC5	555

Miscellaneous

ETI-330 pc board; 12 V single changeover contact (10 A rating) pc mounting relay (such as the Fujitsu FRL611DO12 or similar); diecast aluminium box 120 mm long by 95 mm wide by 40 mm deep or similar; 10-way terminal strip; DPST or TPST toggle switch (for concealed switch); length of automotive electrical cable; sundry nuts and bolts.

Price estimate

We estimate that the cost of purchasing all the components for this project will be in the range:

$25 - $32

Note that this is an **estimate** only and **not** a recommended price. A variety of factors may affect the price of a project such as — quality of components purchased, type of pc board (fibreglass or phenolic base), type of front panel (if used) supplied etc — whether bought as separate components or made up as a kit.

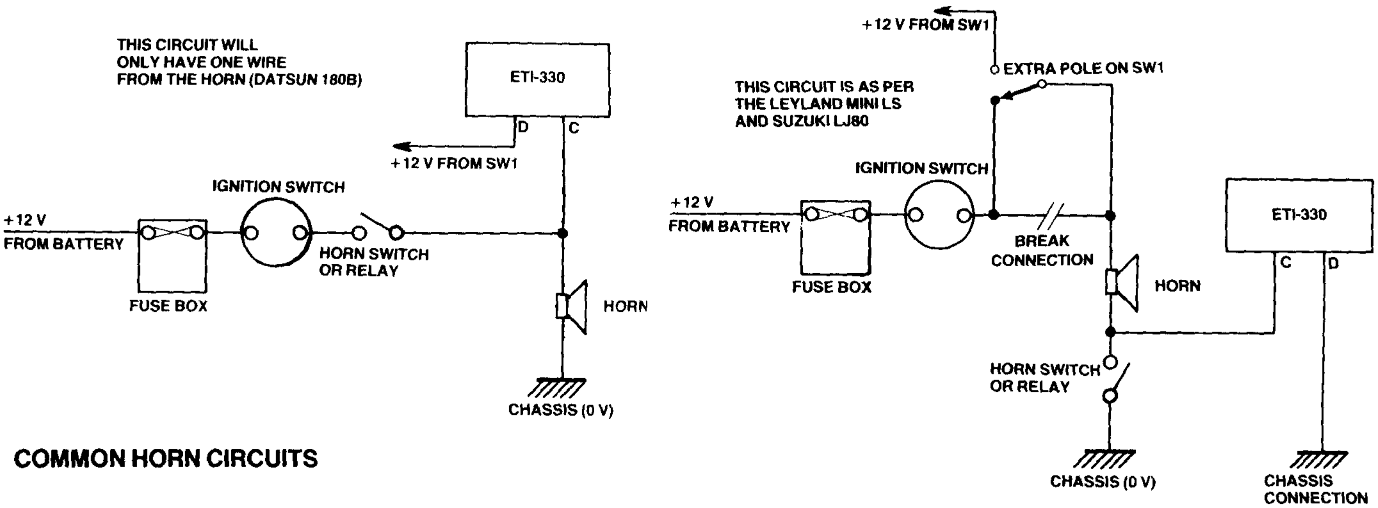
Installation

Firstly, mount the 'Alarm On' LED (the one that flashes) and the 'Alarm Tripped' LED on the dash in convenient positions where they can be seen from outside the vehicle. You can obtain LEDs mounted in metal and plastic mounting which is secured by a nut or clip, and these are ideal for this application.

The alarm is switched on by a concealed switch which may be located under the dash or under the driver's seat. Alternatively, an externally mounted keyswitch may be used. If you install the latter, entry and exit delay may be reduced to about half a second by changing the value of C1 to 1u.

We used a two-pole switch, one pole to switch the supply to the alarm, the other to short out the points when the alarm is switched on. Thus, if somebody does gain entry to the car and ignores the alarm or disconnects the horn, they will not be able to start the car even if they jumper the ignition!

Connection to the earth strap is quite straightforward. Take a wire from terminal A and solder it to the end of the earth strap. Terminal B is taken and



COMMON HORN CIRCUITS

soldered to the battery terminal connection. It's a good idea to keep these leads fairly short to reduce noise pickup. Ours were about one metre long.

The positive supply, via the alarm switch, should be taken through an inline fuse holder, directly from the battery positive terminal. The normal fuse holder in a car is usually under the dash and could easily be pulled out by a thief when the alarm goes off.

The output from the alarm is a pair of switched contacts, which operate the horn by bypassing the horn switch or, on some cars, the horn relay. We have shown two common horn circuits. The the first circuit the horn switch is bypassed by the relay contacts. The second circuit is a little more complex and requires an extra pole on the alarm switch. If you want to short out the points as well you will need a three-pole double-throw switch. Make sure you break the connection from the ignition switch to the horn as shown, or when you switch the alarm on you will also switch on the ignition!

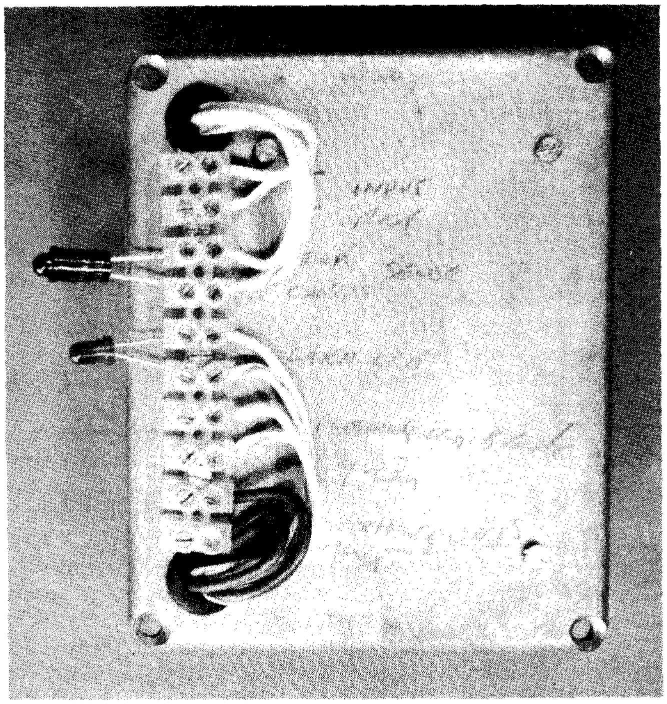
Try to make all wiring as neat as possible and try to blend it in with the car's wiring so it is not obvious to a thief what wire he has to pull out to stop the alarm.

Setting up

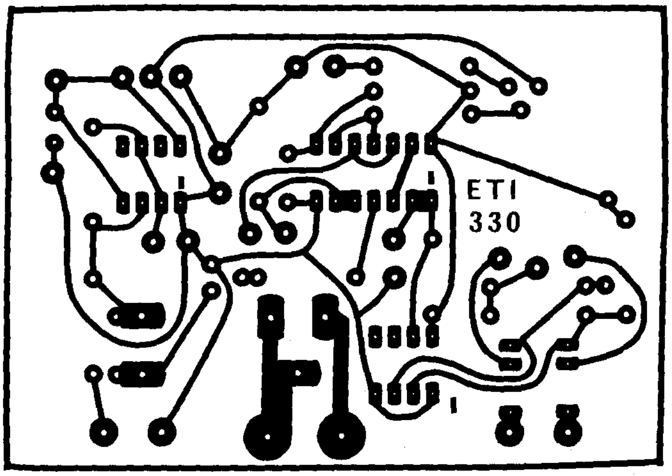
When all the wiring is complete, all that remains is to set the sensitivity trimpot. Disable the entry and exit delay by removing C1, or alternatively connect a high impedance voltmeter across C1. With no current being drawn from the battery, adjust RV1 until the alarm just fails to trip or C1 fails to start to charge. Note the position on the trimpot. Turn on the interior light and the alarm should trip. If it does not, check your first adjustment; if it is correct, you probably have the leads to the earth strap and the battery negative terminal swapped.

Turn the trimpot until the alarm just won't trip or C1 doesn't charge when the interior light is turned on. Note this position. The correct position for RV1 is midway between these limits, for reliable operation.

Next check that the alarm doesn't trip on the car radio or the electric clock. Some mechanical clocks are rewound by a motor every few hours, or even days, and these are often a cause of false triggering. If false triggering occurs from the radio or the clock, reduce the sensitivity. In some extreme cases it may be necessary to use a higher wattage interior light, though I found operation to be extremely reliable with a five watt light, and there was sensitivity to spare! ●



Everything is mounted on the lid of the diecast box and terminations made via a 10-way terminal block mounted on the outside of the lid. Mark each lead, especially polarity where necessary.



Project 570

Infrared 'trip' relay

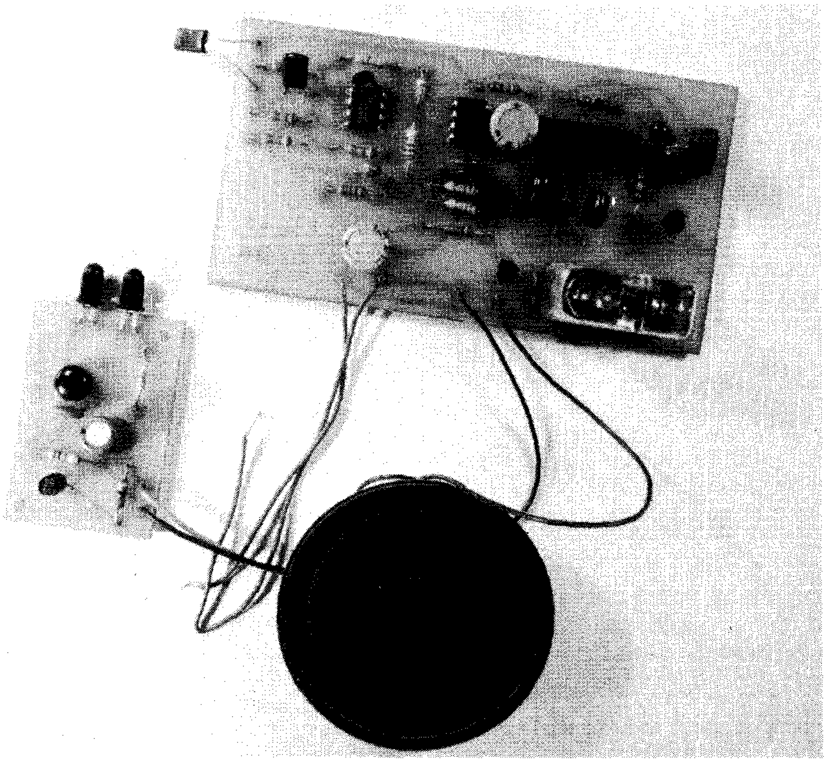
Cut the beam of invisible light and 'trip' a relay or alarm — this simple project can be used as an automatic 'door minder', door opener, a burglar alarm or whatever.

Phil Wait
William Fisher

EVERYONE is familiar with the kind of door that's operated by an invisible beam. As you approach the door your body interrupts the beam, which triggers a switch to open the door. The same principle can be used for other things as well, like a 'door minder' alarm. The beam is set up across the doorway and when a person walks through it an alarm is set off.

This project is the basis of such a system. It comprises a transmitter which emits a beam of infrared radiation and a receiver which detects that radiation. As long as the receiver continues to receive the radiation nothing happens, but if the beam is interrupted a relay is energised (or 'tripped') and latched on for a fixed period of time. The contacts of this relay could carry the current for any 12 volt device, like a lamp, a piezoelectric siren, a small motor or whatever the application calls for. At the same time as the relay is energised, a low-level oscillator is switched on so that a buzzing noise can be heard through a loudspeaker if this is wanted.

The infrared beam is produced by two infrared light emitting diodes. These are just like any other LED, except that the light they emit has a longer wavelength. They use quite a lot of current, so to prevent batteries going flat too quickly they are supplied with very brief pulses of current at intervals of a few milliseconds, so that they emit short, intense bursts of radiation. This also makes it easier to detect the radiation. The range of the system is about two metres, which we thought was adequate for many applications. You could increase the range to about three metres by using two transmitters instead of one, but to increase it further requires a disproportionate amount of power. The range is inversely proportional to the square of the radiated power, so that doubling the range means quadrupling the amount of radiation transmitted, tripling the range means increasing the transmitted radiation by nine times, and so forth.



Construction

We recommend that you use our designs of printed circuit boards to construct the transmitter and receiver, but they are not essential.

Start by mounting the resistors on both boards, referring to our layout diagrams for their positions. Like all the components, these go on the plain side of the board, with their leads pushed through the holes and soldered to the tracks on the other side. Next, solder in all the capacitors on both boards, making sure that all the electrolytic or tantalum capacitors are correctly oriented with their positive leads at the ends we have shown.

Now mount the two infrared LEDs (LED1 and LED2) on the transmitter board. They must go in the right way round, with their cathodes (marked k on our diagrams) at the correct end. After that, mount the two transistors on the transmitter board (Q1 and Q2), making sure that their base, emitter and collector leads (marked b, e and c on our diagrams) are in the correct positions.

Turning to the receiver board, mount the two potentiometers (RV1 and RV2), then insert the diode (D1) and the infrared detecting diode (IRD1), making sure their cathodes are at the correct ends. In the case of IRD1 you also have to make sure that the sensitive side of the diode faces away from the board so that it can be pointed at the transmitter. The diode has two faces, one flat and one bevelled near the top, the flat side being the sensitive side. Mount IRD1 high enough above the board for it to be bent over to face the proper way.

Then mount the two transistors (Q1 and Q2), making sure you get all their leads in the right places. After that you can tackle the integrated circuits (IC1, IC2 and IC3). Make sure you put them in with the notch or spot at the same end

PARTS LIST — ETI 570

ETI-570a Transmitter

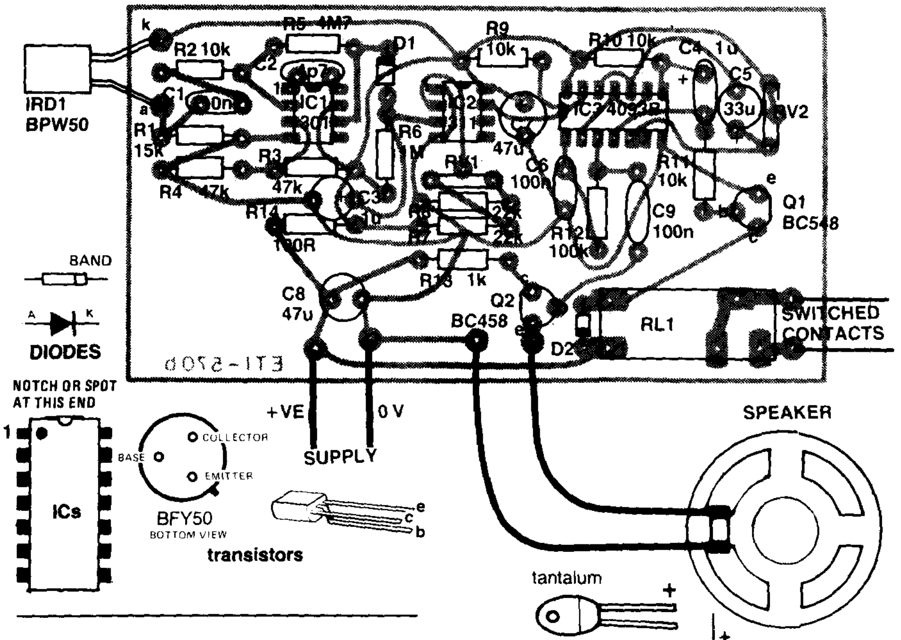
Resistors	**all ½W, 5%**
R1	47R
R2	10M
R3	3R3
Capacitors	
C1	1n greencap
C2	100u/16 V electro.
Semiconductors	
LED1,2	CQY89A or similar
Q1	BC558, BC178 or similar
Q2	BFY50 or similar

Miscellaneous

ETI-570a pc board; case to suit, etc.

ETI-570b Receiver

Resistors	**all ½W, 5%**
R1	15k
R2,R9-R11	10k
R3, R4	47k
R5	4M7
R6	1M
R7, R8	22k
R12	100k
R13	1k
R14	100R
RV1	100k min. vertical mount trimpot.
RV2	1M min. vertical mount trimpot.
Capacitors	
C1	10n greencap
C2	4p7 ceramic
C3, C4	1u/16 V tantalum
C6, C9	100n greencap
C5	33u/16 V tant, or RBLL
C7, C8	47u/16 V electro
Semiconductors	
D1	1N914,1N4148 or sim
D2	1N4002, etc.
IRD1	BPW50 or similar
Q1,Q2	BC548,BC108 or similar
IC1	301
IC2	311
IC3	4093B



Miscellaneous

RL1	SPDT pc mount relay with 12 V coil

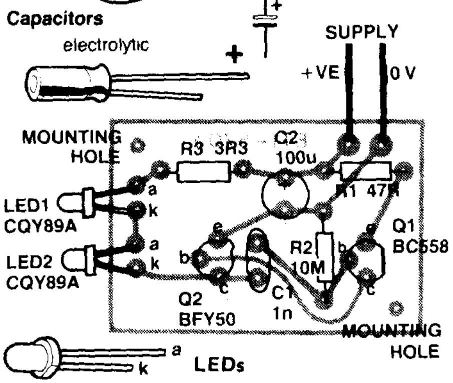
ETI-570b pc board, miniature 8 ohm speaker, case to suit, etc.

Price estimate

We estimate the cost of purchasing all the components for this project will be in the range:

$21—$25

Note that this is an **estimate** only and **not** a recommended price. A variety of factors may affect the price of a project, such as — quality of components purchased, type of pc board (fibreglass or phenolic base), type of front panel supplied (if used), etc — whether bought as separate components or made up as a kit.



as our layout diagrams show, and take care when soldering them in that you don't overheat them. Use a reasonably small bit, don't spend too long over each pin and allow the whole IC to cool down for a few seconds between soldering each of the pins.

Finally mount the relay, connect the loudspeaker to the board (using insulated hookup wire), attach two insulated leads for the power supply, and attach the battery clip to the transmitter board. The transmitter and receiver are now both completed.

Setting up

Connect a 12 volt battery or power supply. Adjust RV1 for minimum resistance. With the transmitter turned off, increase the value of RV1 until the relay just operates. You will notice that the relay will switch off as the latch resets at the end of the timing period, then switch on again as the latch is set again.

Turn on the transmitter and move it away from the receiver, keeping the two LEDs pointing towards the receiver all the time. You should be able to move two metres away without anything happening. If you find that the receiver is not sensitive enough, you can add another infrared receiving diode in parallel with IRD1 to increase the amount of radiation it picks up. If the range is OK, check that the relay operates when the beam is broken.

The volume of sound from the speaker can be altered by altering the value of R13. Reducing the value of R13 increases the volume, increasing R13 reduces it. You can also vary the time that the relay contacts are closed by varying the setting of RV2.

Housing

As individual applications of this project will vary widely, we have not described how to house it in any specific way. However, a few hints may help. The transmitter could be housed in any convenient small container, such as a jiffy box or even a cheap plastic soapholder from a chain store. The two infrared LEDs can be mounted in any convenient position, secured with common LED 'collar' mounts. When mounting the LEDs, keep in mind how you will mount the transmitter box so that the LEDs face in the desired direction.

The receiver can also be mounted in any suitable housing. The infrared receiver diode may be mounted off the pc board or the board positioned so that the diode is held against a hole cut in one side of the case. Alternatively, the receiver diode may be mounted on a tagstrip bolted in an appropriate position. You can secure a small piece of infrared filter plastic over the hole in the case. This will provide some physical protection for the diode. Kodak 'Wratten 89c' or a similar type of filter plastic will do. Make sure you correctly identify the sensitive face of the diode.

For outdoor applications, where the units may be exposed to the weather, we recommend you use aluminium diecast boxes. They're more expensive than other housings, but they're very robust and can be sealed against the weather. ▶

HOW IT WORKS

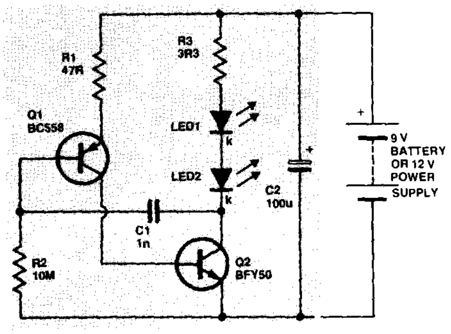
TRANSMITTER

A serial multivibrator allows frequent short pulses of current through two infrared LEDs, so that they emit pulses of radiation towards the receiver. To ensure a reasonable battery life, the duration of each pulse is kept short compared to the interval between pulses. Because the pulse length is short, the LEDs can pass a current of more than one ampere without burning out, thereby producing a high level of radiation that can be detected at a distance of about two metres. The radiation output is further increased by using two LEDs in series.

When the circuit is turned on, the base of Q2 is at a low voltage and Q2 is therefore turned off. This means that Q2's collector is at a voltage close to the battery supply voltage. A small current therefore flows through R3, LED1, LED2, C1 and R2 to ground. The voltage drop across R3 caused by this current keeps the base of Q1 at a 'high' voltage, so that Q1 is turned off. As C1 charges, it develops a voltage across its plates that opposes the flow of current through R3. The voltage on the base of Q1 therefore starts to drop, and when it has dropped about 0.7 volts below the supply voltage, Q1 turns on. This allows current to flow through the base-emitter junction of Q2 and turn that transistor on also, so that a large current can flow through R3 and the two LEDs.

The current through Q2 is large because of the low value of R3, and the high internal resistance of the battery means that it cannot supply this current without a considerable drop in the voltage across its terminals. The current therefore comes mainly from the discharging of capacitor C2. Once C2 has discharged, the low voltage across the battery terminals cannot drive enough current through R1 and Q1 to keep Q2 turned on, so this transistor turns off again, cutting off nearly all the current through the LEDs and allowing the battery voltage to rise again.

While Q2 is turned on, its collector voltage is low, which allows C1 to discharge, so that when Q2 turns off again the circuit is in the same state as it began in and the whole cycle repeats itself over and over again until power is turned off. The frequency of the pulses depends on the time taken for C1 to charge (which depends mainly on the battery voltage and the values of C1 and R2). The duration of each pulse depends on the time taken for C2 to discharge (which depends mainly on the battery voltage and the values of C2 and R3). The values we have specified for components give pulses a few microseconds long at intervals of a few milliseconds. The peak current through the LEDs is about one amp, but the average current is only about one milliamp.



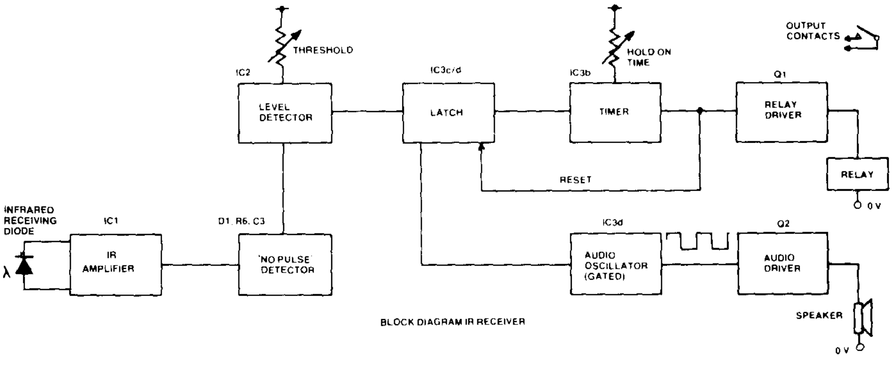
INFRARED TRANSMITTER

RECEIVER

The pulses of infrared radiation emitted by the transmitter are detected by an infrared receiving diode and amplified by an op-amp. The output pulses from the op-amp are used to keep a capacitor discharged, and a comparator IC compares the voltage across this capacitor to a reference voltage. As long as the reference voltage is higher, the comparator puts out a 'high' voltage and nothing happens. When the infrared beam is interrupted, there are no current pulses to keep the capacitor discharged, so its voltage rises and the comparator output swings low. This low voltage operates a latch, one of whose outputs switches on a transistor to allow current through a relay to close its contacts. The other latch output switches on an oscillator to produce a tone in a loudspeaker. When a set period of time has expired, the latch is automatically reset, cutting off current to the relay and loudspeaker.

When a pulse of infrared radiation strikes the receiving surface of the reverse-biased infrared receiving diode (IRD1), it conducts a pulse of current. The voltage drop across R1 caused by this current pulse is applied to the inverting input of op-amp IC1 via coupling capacitor C1. The non-inverting input of IC1 is held at a steady voltage by the potential divider R3 and R4. Negative feedback through R5 sets the gain of IC1 at around 500. Since the input pulses are applied to the inverting input of IC1, the amplified output pulses are negative-going.

The diode D1 passes only the negative pulses, which discharge capacitor C3. Because R6 has a high value, C3 cannot charge much between pulses, so that a continuous series of pulses from the transmitter keeps C3 discharged, with a low voltage across its plates. If the beam from the transmitter is interrupted, C3 charges up and the voltage across it rises.



BLOCK DIAGRAM IR RECEIVER

IC2 is a comparator. Its output (at pin 7) is high when the voltage on pin 2 is higher than the voltage on pin 3. If the voltage on pin 3 is higher than the voltage on pin 2, the output of IC2 is low. Pin 2 is held at a constant preset voltage by the potential divider chain of R7, RV1 and R8. When pulses are being received, C3 is discharged and the voltage on pin 3 is therefore low; when the beam is interrupted, C3 charges up and the voltage on pin 3 rises, switching the output of IC2 from high to low.

IC3b, IC3c and IC3d are Schmitt-triggered NAND gates connected as a latch circuit. If either of the inputs of a Schmitt-triggered NAND gate is low, then its output is high. If both inputs rise above a 'threshold' voltage, the output goes low. If either input then falls below a second threshold voltage, the output goes high again.

When power is first turned on to the circuit, pins 5 and 6 of IC3b are held high via RV2, so that its output (pin 4) is low. This means that current can flow through R10 and C4 to pin 4 of IC3b and the voltage drop across R10 caused by this current makes pin 8 of IC3c go low. Output pin 10 of IC3c therefore goes high and so does input pin 12 of IC3d. If pulses are being received from the transmitter, pin 13 of IC3d is also high, so that output pin 11 is low. Input pin 9 of IC3d is therefore held low also, and this low on pin 9 keeps the output of IC3c high, even after pin 8 goes high again, because capacitor C4 has charged up and stopped current flowing through R10.

When the pulses are interrupted, pin 13 of IC3d goes low, sending output pin 11 high. Pin 9 therefore goes high too and since pin 8 is also high, output pin 10 goes low. Current then begins to flow through RV2 and C5 to pin 10, causing a voltage drop across RV2 which sends pins 5 and 6 of IC3b low. Output pin 4 of IC3b therefore goes high and current flows from this pin through R11 to turn on transistor Q1, allowing current through the relay to close its contacts. At the same time, the high on pin 11 of IC3d is applied to input pin 2 of IC3a, which is another Schmitt-triggered NAND gate configured as a square wave oscillator. Capacitor C5 slowly charges up from current through RV2, developing an increasing voltage across its plates. After a while, the voltage on C5 forces the inputs of IC3b above the threshold voltage and its output (pin 4) goes low, cutting off the bias current to Q1, which therefore turns off and stops current to the relay so that its contacts open again. The low on pin 4 of IC3b allows a pulse of current to flow through R10 and C4, which resets the latch.

When pin 2 of IC3a goes high, the other input (pin 1) is initially low, so that output pin 3 is high. This allows current to flow from pin 3 through R12 and C6 to ground. At first the voltage drop across R12 caused by this current keeps pin 1 low, but after a short time C6 has charged up and developed a voltage across its plates which forces pin 1 above the threshold level. Pin 3 therefore goes low and C6 discharges into it through R12. As C6 discharges, its voltage drops and after a little while pin 1 drops below the threshold, so that pin 3 goes high again. The oscillator is then in the same state it began in and the process repeats itself over and over again, producing

SILICON PHOTO P-I-N DIODE

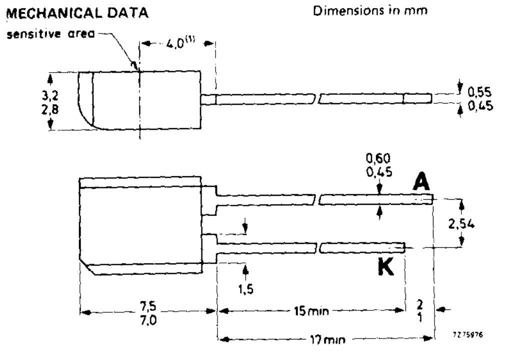
Silicon photo p-i-n diode in a plastic envelope with an infrared filter.

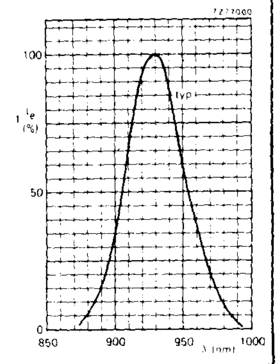
QUICK REFERENCE DATA

Continuous reverse voltage	V_R	max.	32 V
Total power dissipation up to T_{amb} = 47,5 °C	P_{tot}	max.	150 mW
Junction temperature	T_j	max.	100 °C
Dark reverse current V_R = 10 V; E_e = 0	$I_{R(D)}$	<	30 nA
Light reverse current V_R = 5 V; E_e = 1 mW/cm²; λ = 930 nm	$I_{R(L)}$	>	30 μA
Wavelength at peak response V_R = 5 V	λ_{pk}	typ.	930 nm
Sensitive area	A	typ.	5 mm²

MECHANICAL DATA

Dimensions in mm



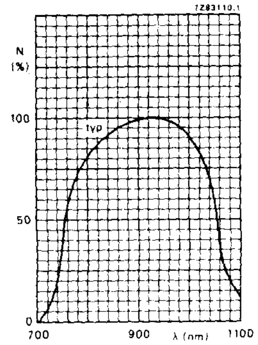


GaAs LIGHT EMITTING DIODE

Epitaxial gallium arsenide light emitting diode intended for remote-control applications. It emits radiation in the near infrared when forward biased. Infrared translucent epoxy encapsulation (dark blue).

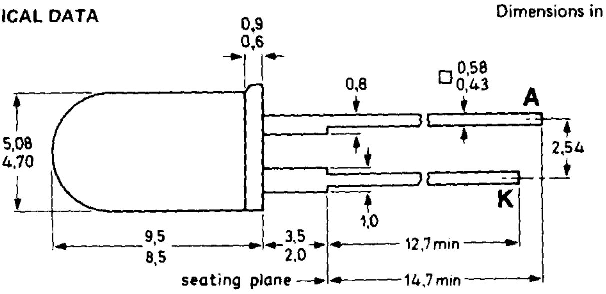
QUICK REFERENCE DATA

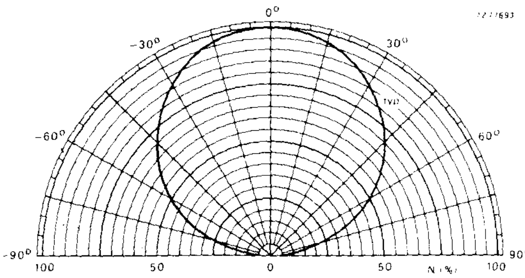
Continuous reverse voltage		V_R	max.	5 V
Forward current (d.c.)		I_F	max.	130 mA
Total power dissipation up to T_{amb} = 25 °C		P_{tot}	max.	215 mW
Junction temperature		T_j	max.	100 °C
Radiant intensity (on-axis) at I_F = 100 mA	**CQY89A**	I_e	>	9 mW/sr
	CQY89A-1	I_e		9 to 20 mW/sr
	CQY89A-2	I_e	>	15 mW/sr
Wavelength at peak emission		λ_{pk}	typ.	930 nm

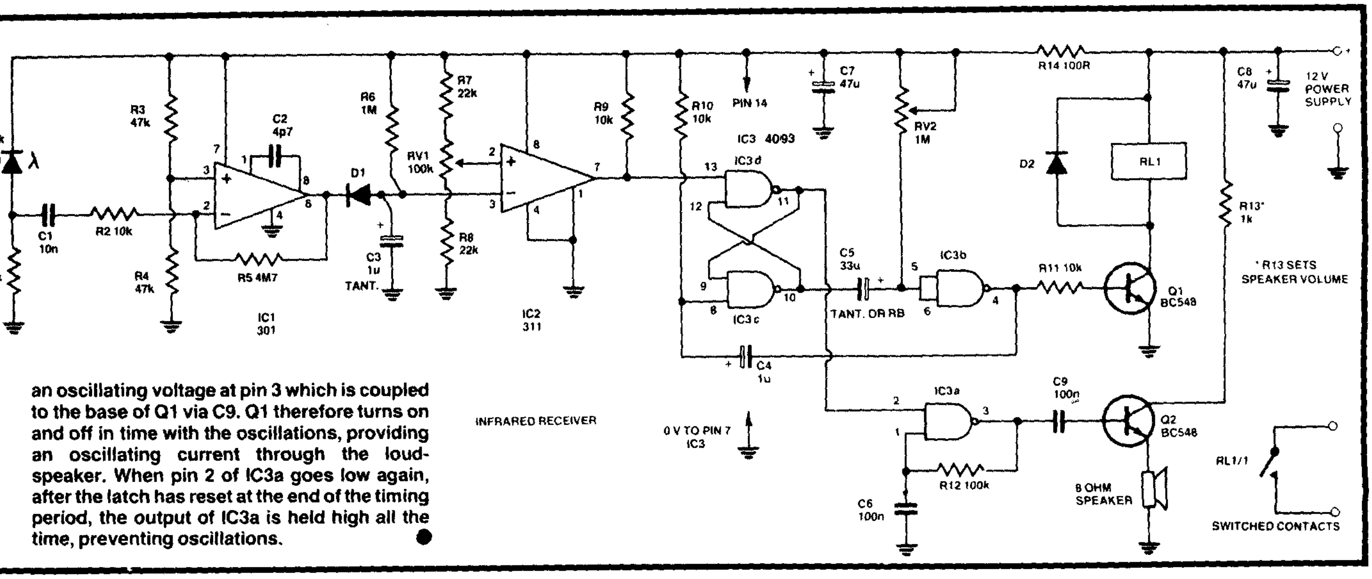


MECHANICAL DATA

Dimensions in mm







an oscillating voltage at pin 3 which is coupled to the base of Q1 via C9. Q1 therefore turns on and off in time with the oscillations, providing an oscillating current through the loudspeaker. When pin 2 of IC3a goes low again, after the latch has reset at the end of the timing period, the output of IC3a is held high all the time, preventing oscillations. ●

Project 1506

Xenon flasher for pushbike riders

If you go riding your pushbike on a dark night during a power blackout, you'll need this project. Even if you just ride your bike at nights, being visible to other vehicles is important for safety. A bright flashing light will see to that.

Jonathan Scott

THIS IS an idea which is only just catching on in the US (so who knows how long it will be before it gets proper commercial release here), and it's a good thing indeed. Let's face it — bicycle lights are pretty useless for seeing things, but they serve the valuable purpose of letting the rider *be seen*. It is also not a recent realisation that a xenon flash is easily seen at a distance and potentially very power economical, which is what you want if you have to purchase (and carry) the batteries.

So here it is: the low-cost, high visibility bicycle flash. It will flash for many hours on one single cell, a Nicad being best as you only have to pay about ten times the initial price for 100-500 times the life.

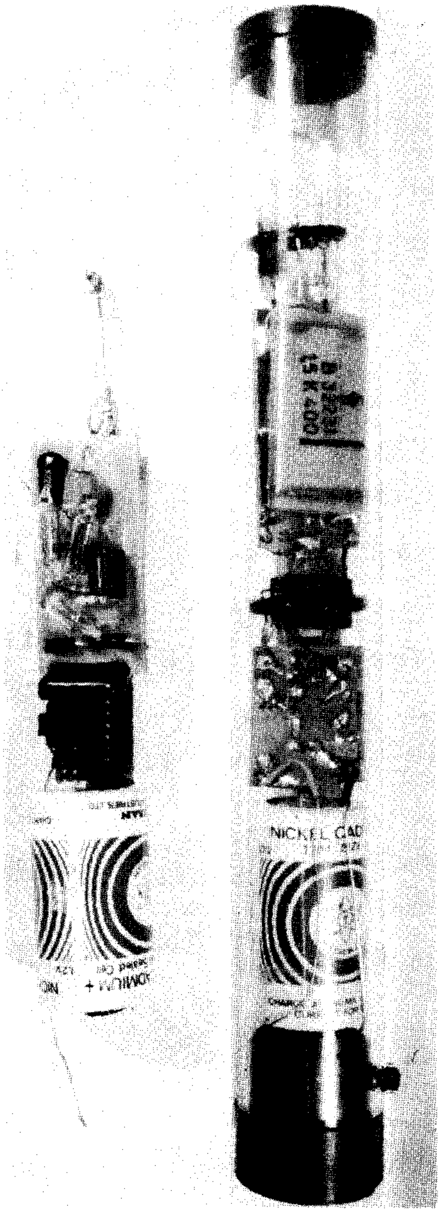
Our prototypes, one constructed using a dismantled $10 flashgun and one from commercial electronic suppliers' parts, ran for 15 hours and 8 hours at 1 Hz and 4 Hz respectively, on $7 Nicads. One quarter of this can be expected from $2 Nicads.

The unit can be recharged from any convenient source including the ETI-563 Fast Nicad Charger, a bicycle dynamo, or the charger we include in this project.

Bits and pieces

As we mentioned before, we have built one 1506 using parts from a $10 flashgun purchased expressly for this purpose. The advantage of this is that you get the xenon tube, trigger transformer and neon lamp all customised and prepacked. You also get a prewound converter transformer, though we recommend that you wind your own, as we did, as the result is about twice as power efficient.

Alternatively the project can be made entirely from easy-to-find parts, with one small circuit modification. Perhaps at this stage you are rather confused by all the options, so let's break the project up into its two basic sections and describe how you go about each part.



Two versions of the Flasher. On the left, one from a junked photo flashgun; on the right, from over-the-counter parts.

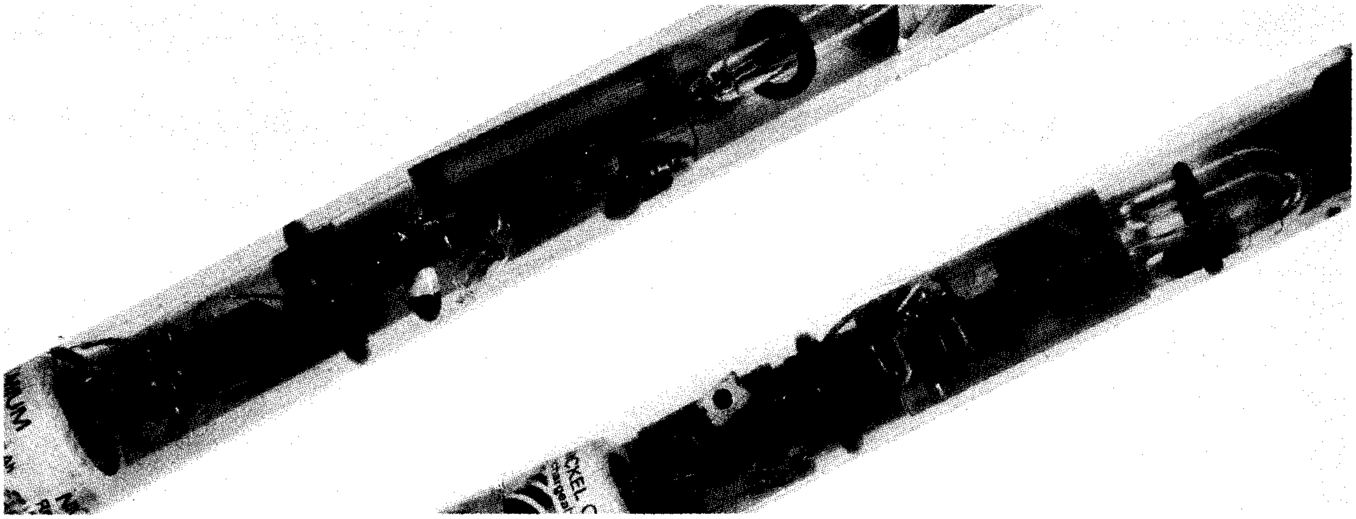
Our preference

Referring to the circuit in Figure 1, which is our preferred and recommended circuit, you see that it is composed of a dc-ac converter board (taken directly from the ETI-575 Light Wand) and its transformer, and an ac-dc flash driver board. Starting with the latter, if you then have or purchase a cheap flashgun, you will also have the tube, trigger transformer and 220 V neon.

The small flash-type xenon tubes seem to be slightly more light-efficient than the 'U'-tube type locally sold, and are less easily broken, so we prefer them. If you don't get hold of it this way you may have difficulty getting the neon, so we have made provision on the pc board for using three of the local 70 V type (NE2) in series, in place of the single 220 V one.

An advantage of using the 220 V tube is that it delivers a non-regular flash rate, which we feel improves recognisability and reduces risk of confusing you on the bicycle with any other flashing light. We won't go into the physics of why the xenon tube does this, but suffice it to say that the 70 volt types do not have sufficiently significant erratic factors to give a visibly varying rate over short time periods.

If you use the three neons in series, you will have to cut off the SCR's heatsink tab to make the necessary room. This is quite safe, as it dissipates negligible power. See the two overlay diagrams for details of this. The tab can be removed by hacksaw, side cutters or simply by bending it until it fatigues, as it is made of thin, soft metal. This should present no problem. ▶



Inside views of the 'preferred' flash unit.

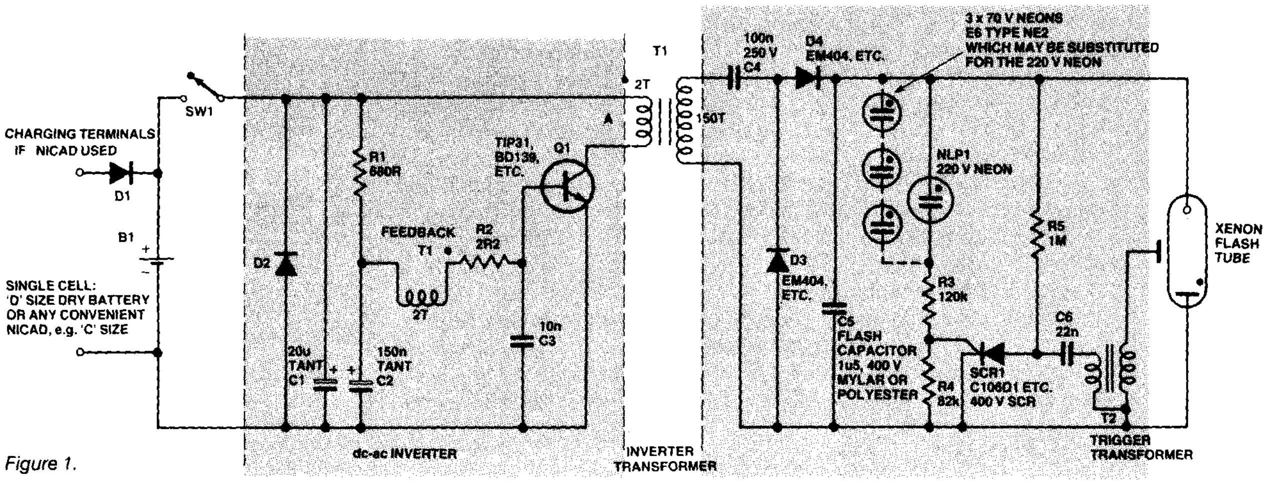

SW1
CHARGING TERMINALS IF NICAD USED
D1
B1
SINGLE CELL: 'D' SIZE DRY BATTERY OR ANY CONVENIENT NICAD, e.g. 'C' SIZE
D2
20u TANT C1
150n TANT C2
R1 680R
FEEDBACK T1
2T
R2 2R2
10n C3
TIP31, BD139, ETC.
Q1
A
2T
150T
T1
dc-ac INVERTER
INVERTER TRANSFORMER
100n 250 V C4
D4 EM404, ETC.
D3 EM404, ETC.
C5 FLASH CAPACITOR 1u5, 400 V MYLAR OR POLYESTER
3 x 70 V NEONS E6 TYPE NE2 WHICH MAY BE SUBSTITUTED FOR THE 220 V NEON
NLP1 220 V NEON
R3 120k
R4 82k
SCR1 C106D1 ETC. 400 V SCR
R5 1M
C6 22n
T2
TRIGGER TRANSFORMER
XENON FLASH TUBE

Figure 1.

HOW IT WORKS — ETI 1506

There are two major sections to the circuitry: first the dc-ac inverter, followed by the xenon flasher.

INVERTER

This employs the inverter circuit from the ETI-575 Light Wand (ETI, Aug. '79). This section of the circuit is shown on the left in Figure 1. R1, R2, C2, C3, Q1 and T1 comprise a self-oscillating dc-ac inverter.

Initially, Q1 is turned off. At switch-on, current flows through R1, charging C2. Subsequently C3 charges up via the feedback winding and R2. When C3 reaches about 0.55 volts, Q1 begins to conduct. The feedback winding then forces more current into C3 via R2 because of the phase of its connection. Q1 is then turned hard on. During this positive feedback cycle C2 is actually forced to discharge. R2 limits the maximum base current, and C3 removes fast spikes from the base circuit. These together serve to protect Q1's base.

Eventually, the magnetic field induced by the collector current of Q1 in the primary ceases to increase and the positive feedback ceases. Q1 then begins to turn off and the magnetic field in the core begins to collapse. This produces a negative voltage across the feedback winding which biases Q1 hard off. Then the cycle repeats, R1 and C2 defining the frequency and the power delivered to the tube, since a constant amount of energy (equal to I^2 max times L) is transferred to the load each cycle.

XENON FLASHER

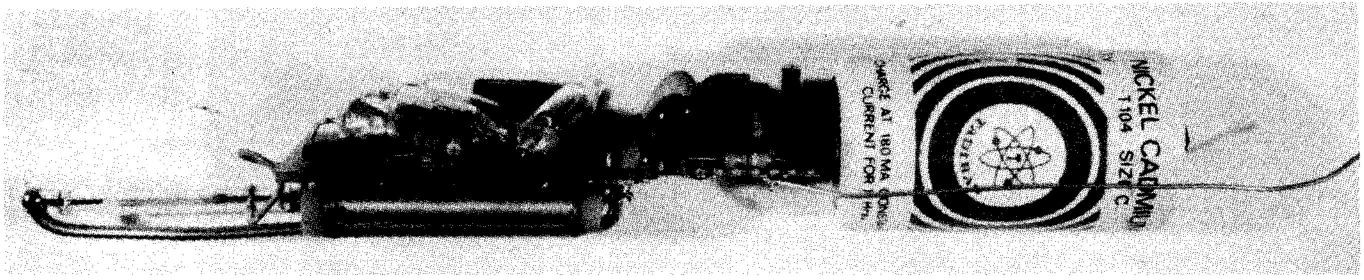
This part of the circuit is shown on the right in Figure 1. C4, C5, D3 and D4 form a 'diode pump', which rectifies the ac output from the secondary of T1 and will 'fill' C5, the 'reservoir capacitor', after a number of cycles, raising the voltage across it to the peak-to-peak input voltage. On negative excursions of the voltage from the secondary of T1, C4 charges via D3. On positive excursions, the charge in C4 is transferred via D4 to C5, and C4 is reverse charged. The period taken to charge C5 is of course dependent on its capacitance and the peak input voltage, which varies because of the inverter's output impedance. However, C5 will, after some time, exceed the 'breakover' voltage of the neon, NLP1 (or the string of three neons). This then conducts, triggering the gate of SCR1, via R3/R4. Resistor R4 prevents false triggering of the SCR by tying it to the cathode with a relatively low impedance.

Before SCR1 triggers, C6 will have charged up to the supply voltage on C5, via R5 and the primary of T1. When SCR1 fires it suddenly connects C6 directly across the primary of T1, whereupon C6 discharges rapidly, producing a large voltage spike at the secondary. This is connected to a 'trigger' electrode wrapped around the outside of the xenon flash tube, and the voltage stress produced causes the gas inside the tube to ionise. Current then flows between the anode and the cathode of the xenon tube, the gas emitting much light in the process. The current flowing in the xenon tube discharges C5. When the voltage on C5 falls far enough, the xenon tube cannot maintain ionisation and it ceases conducting, as does NLP1. The SCR1 will also return to the non-conducting state as less than the anode-cathode latching current required flows through R5. Thus C5 starts re-charging and the whole cycle repeats.

The point at which NLP1 ionises varies with the immediate electrostatic field it is experiencing and also with the ambient radiation level, as these are significant factors in the ionisation process in neon lamps of this type. Thus flashing is erratic when a 220 V neon is used.

The function of diode D1 is to prevent B1 discharging via the charging terminals if they are accidently shorted, while D2 protects Q1 in the event of reverse polarity connection of the battery. (This is particularly likely if you ever use dry batteries, as they are changed often and it's easy to slip them in a battery holder the wrong way round.)

Capacitor C1 provides a low impedance bypass for the supply rail.



Overall view of the Flasher constructed from a cannibalised flashgun.

Converter circuit

Considering the converter circuit, we decided we would build one ourselves and 'borrow' one from a commercial flashgun. Ours turned out to be more power efficient, and quite easily adapted to using only 1.2 V of supply. It is, of course, the more effort-consuming option, as you have to wind your own transformer and make up an ETI-575 pc board, but this is the more pleasing way, electronically speaking.

If you have bought a flashgun that uses one, two or four cells, you must of course use that number if you want to use its transformer. You will have to quickly trace out their circuit to get the pin connections of the transformer before you dismantle it. It is almost certain to look like Figure 2, from which you can get a converter circuit like Figure 3.

Use the original transistor(s) as well if you like. We used a BD139 to show that it too will do the job. We suggest you only undertake this if you know what you are doing tracing around someone else's pc board.

Housing

We elected to build our units in the same perspex tubing which we used for the Light Wand. It has 26 mm inside diameter and 32 mm outside diameter, and so just accommodates the 'C' size batteries neatly. There is no reason why you can't build it in any transparent housing, such as a plastic kitchen container, and use a battery larger or smaller as you wish. A penlight Nicad will comfortably run the unit, though not for as long as a 'C' cell, as its capacity is 0.45 Ah rather than about 1.8 Ah (if you have the high density ones).

The charger circuit supplied here is specially designed to charge a single or two 1.8 Ah batteries, and is thus suitable for the units as we have built them. A dynamo on a bicycle may also be used, connected directly to the charging terminals. The series charging diode must be a 3 A type.

One last note. C5, the flash capacitor, can be any value from 0.5 uF to about 10 uF. We used 1.5 uF. The larger its value, the brighter the flash, but the less frequent. 1.5 uF gives about 3-4 Hz, visible for at least a kilometre of open ground. You may select the capacitor you use for its physical convenience, as we did.

INVERTER TRANSFORMER, T1 WINDING DETAILS

Potcore

Phillips P26/16, 3H1 material, ue68 potcore with single section former, No. 4322-022-28250. Alternatively, a P18/11, 3H1 material, ue1750 potcore could be used. It is physically smaller, which may be an advantage.

Secondary winding

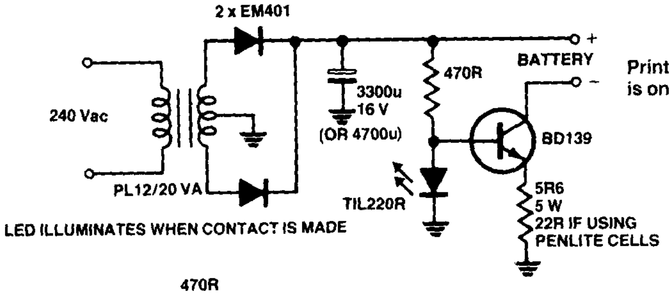
This should be wound first. Wind on 150 turns of 0.2 mm diameter enamelled copper wire (32 B&S), close-wound in layers. As you complete a layer, wrap a length of sticky tape over it before winding the next layer. You'll take about four to six layers. Put a layer of sticky tape over the completed winding.

Primary and feedback

These are wound *bifilar* — two lengths of wire wound side by side. Two turns are required. Use any convenient wire diameter greater than or equal to 0.5 mm (e.g: 22 B&S enamelled copper). **Note:** Mark the *start* leads of each winding — these correspond to those points on the circuit marked with a '•'.

If you've never done this sort of thing before, the article on the ETI-575 Light Wand (August '79) gives a detailed description of the sort of technique employed.

Charger for Nicads suitable for the Flasher



Printed circuit board artwork is on page 124.

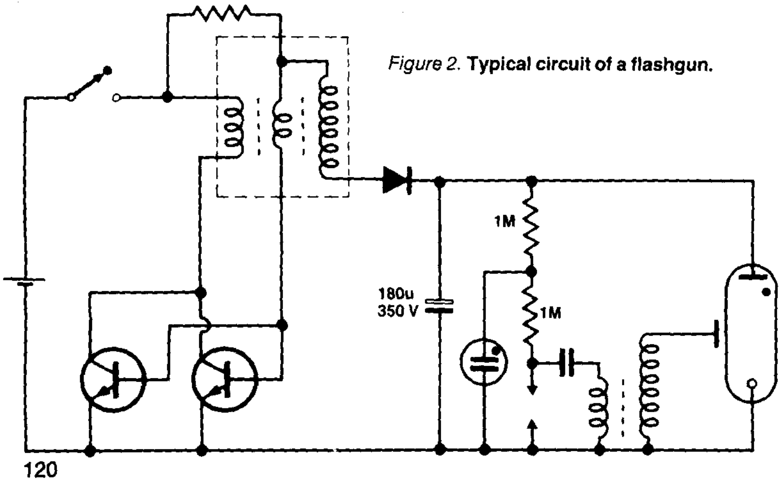
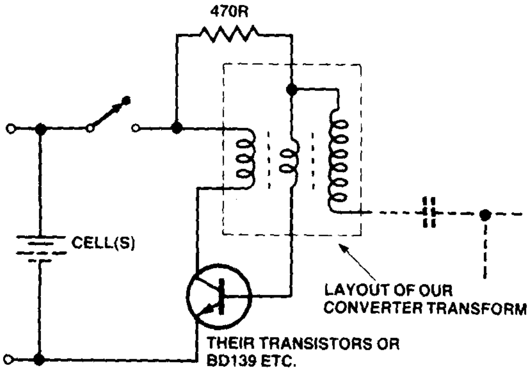
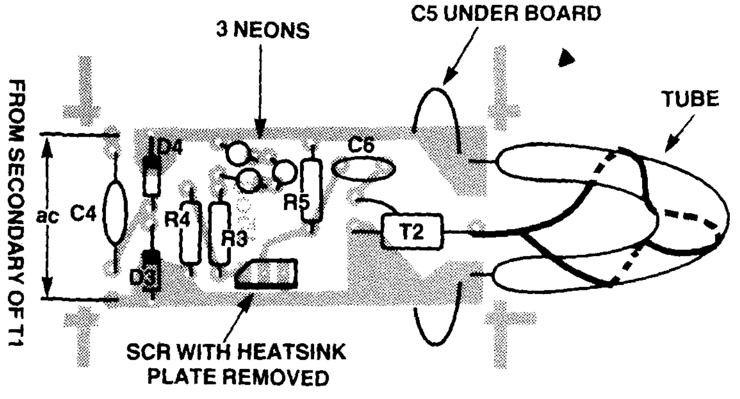


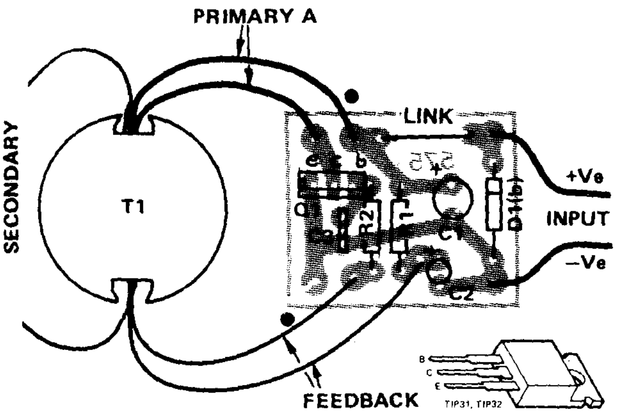
Figure 2. **Typical circuit of a flashgun.**

Figure 3. **Converter circuit from typical flashgun.**





1506 PCB OVERLAY — USING 3 NE2 NEONS



Construction

Construction is best commenced by winding the converter transformer, T1, if you're not using one from a cannibalised flashgun. Details are given in the accompanying panel. Having wound this, carefully scrape about 10 mm of the enamel from the end of each wire and tin carefully. Make sure you have the leads clearly identified.

The inverter board should now be assembled. This employs the ETI-575 pc board, and the accompanying component overlay shows the general construction and wiring. As usual, watch component orientation with D2, Q1, C1 and C2.

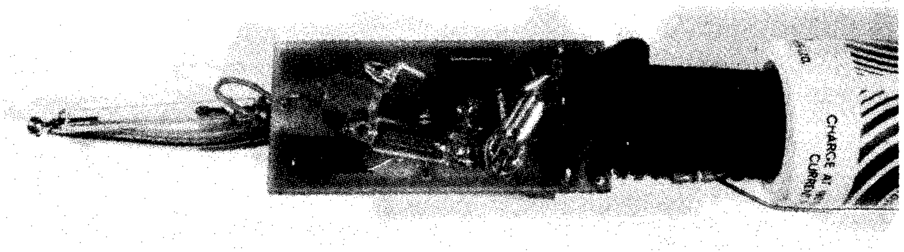
The flasher board can now be assembled. The component overlay shows general assembly for the U-shaped tube, but accompanying photographs show how a straight tube from a flashgun was mounted. Note that the discharge capacitor, C5, is mounted on the 'underside' of the pc board (i.e: copper side). Again watch the orientation of semiconductors. If you've gutted a flashgun, the single 220 V neon mounts between the free end of R3 and the track to the cathode of D4.

With the U-shaped flash tube, note that a length of tinned copper wire needs to be wrapped around the tube as a trigger electrode, and connected to the secondary of the trigger transformer, T2.

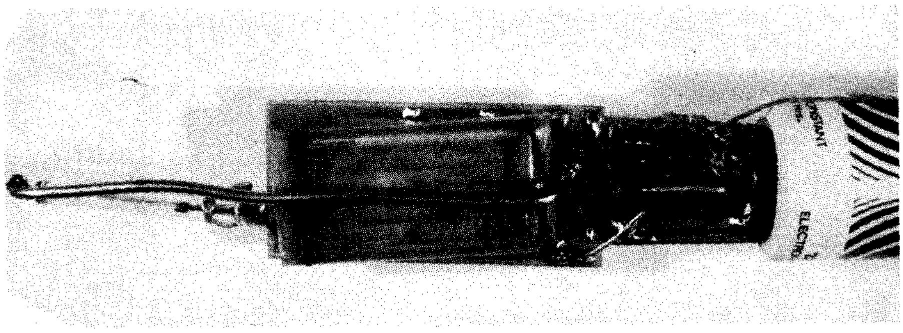
Once it's all together, apply power and see that it flashes as desired. If not, check the voltage across C5. If nothing there, reverse the feedback winding connections on T1 and it should work.

The housing is left up to you as individual requirements are likely to vary widely. If you want to mount the project in a perspex tube, the technique is described in the ETI-575 Light Wand article, ETI August 1979, p.55.

Happy flashing! ●



Close-up of Flasher construction from gutted flashgun, top side.



Same unit, bottom side.

PARTS LIST — ETI 1506

Resistors	all ½W, 5%
R1*	680R
R2*	2R2
R3	120k
R4	82k
R5	1M

Capacitors	
C1*	20u tant.
C2*	150n tant.
C3*	10n greencap
C4	100n/250 V poly.
C5	1u5/250 V poly. This could be any value from 470n to 10u, at least 250 V or greater rating.
C6	22n/250 V poly.

Semiconductors	
D1, D2	1N5404, A15P; 3 A diode. (1 A type may be used if slow charging only is used)
D3, D4	400 V (PIV), 1 A diodes — EM404 or sim.
Q1	TIP31 or BD139, etc.
SCR1	C106D1 or similar 400 V SCR

Miscellaneous	
T1*	see winding details or text
T2	trigger transformer for xenon flash tube** (e.g: Circuit Components TR4KN)
NLP1	220 V neon or 3 x 70 V NE2 type neons.
B1	single Nicad battery
SW1	SPST miniature toggle switch

Xenon flash tube** (e.g: Circuit Components type MFT1210); ETI-575 and ETI-1506 pc boards; clear case or tube to suit.

* Delete these components if using inverter components from flashgun.

** These components may come from scrapped flashgun.

Price estimate **$25-$28**

Headlight delay unit

With this simple project you can use your car headlights to illuminate your pathway for about 50 seconds; safe on a dark night from the horrors of stumbling into bushes or slipping on those nasty smelly things lying on the footpath. The unit is easy to build and install and switches off automatically.

Jennie Whyte

THIS IS a simple circuit which lets you use your car headlights to light your way. It saves you from falling over rubbish bins or walking into fences on a dark night.

After you have parked your car and turned the delay unit on, the headlights will come on for a pre-set period of about 50 seconds. At the end of this period the unit turns the headlights off automatically. So if you haven't manoeuvred the obstacle course by this stage then you're out of luck.

THE 555 AND HOW IT WORKS

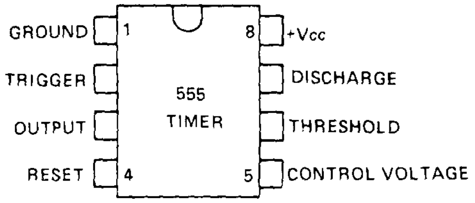


Figure 1.

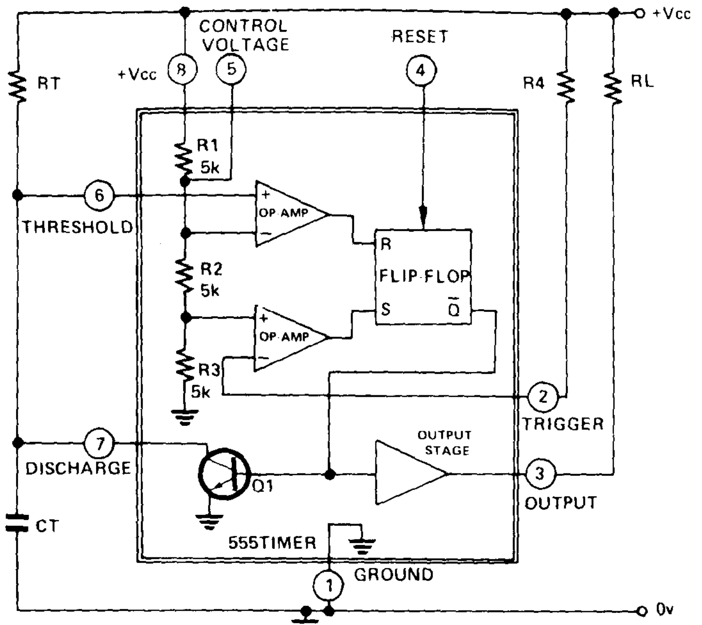


Figure 2.

The 555 timer is a very versatile IC designed specifically for precision timing applications.

It can operate from 4.5 V to 16 V and its output can source (supply) or sink (absorb) any load current up to a maximum of 200 mA. It can directly drive loads such as relays, LEDs, low-power lamps and high impedance speakers.

When used in the 'timing' mode, the IC can produce accurate timing periods variable from a few microseconds to several hundred seconds, via a single resistor-capacitor (RC) network. Timing periods are virtually independent of supply rail voltage, can be started via a 'trigger' command signal and can be stopped by a 'reset' command signal.

The device is available in a number of packaging styles, including 8 and 14-pin dual-in-line (DIL) and 8-pin TO-99 types. Figure 1 shows the outline and pin notations of the standard 8-pin DIL version of the 555. Figure 2 shows the functional block diagram of the same device (within the double lines), together with the connections for using it as a basic monostable generator or timer.

The 555 houses two diodes, 15 resistors and 23 transistors. These components are arranged to form one voltage-reference potential divider, two voltage comparator op-amps, one 'reset-set' (RS) flip-flop, a low-power complementary output stage and a slave transistor.

The period timer, as it is used in the headlight delay unit, gives a direct voltage output at pin 3 which is normally low, but goes high for the duration of the timing period.

The timing action is initiated by momentarily shorting pin 2 to ground via the PB1 START switch. As this voltage is below the reference value of the built-in potential divider the output of the lower voltage comparator op-amp changes state and causes the RS flip-flop to switch over.

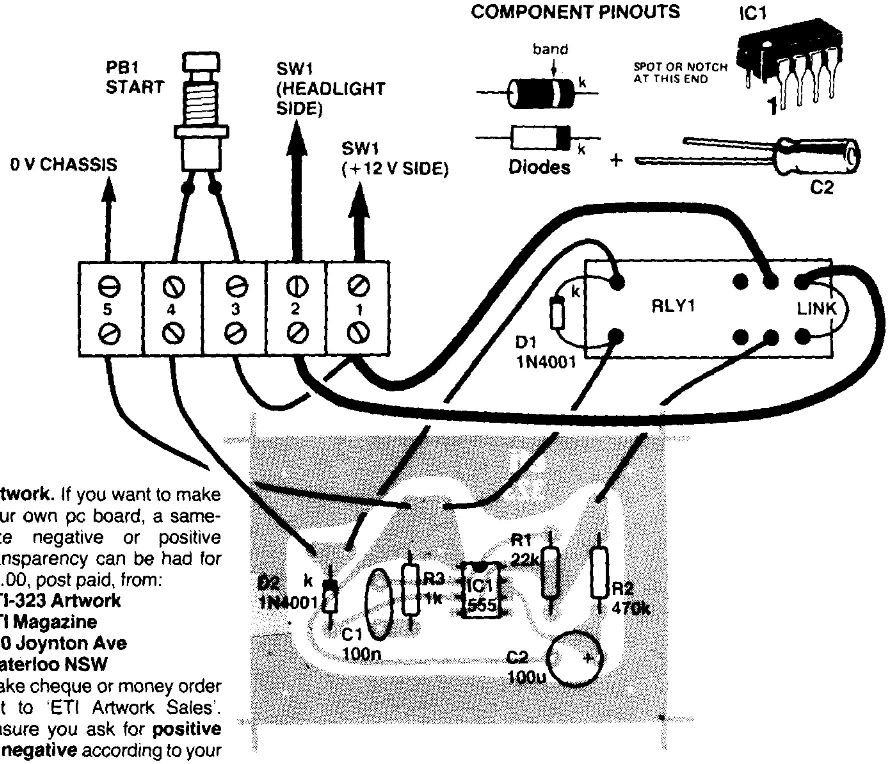
As the RS flip-flop switches over it cuts off Q1 and drives the pin 3 output of the 555 to the high state. As Q1 cuts off it removes the short from the timing capacitor connected to pin 7 and the capacitor starts to charge up. Then the RS flip-flop switches back to its original condition, Q1 turns on, the capacitor discharges and simultaneously the pin 3 output of the IC reverts to its low state.

PARTS LIST — ETI-323

Resistors	all ½W, 5%
R1	22k
R2	470k
R3	1k
Capacitors	
C1	100n greencap
C2	100u/25 V RB electro.
Semiconductors	
D1, D2	1N4001, 1N4002, EM401, EM402, etc.
IC1	uA555, NE555, LM555, DS555, etc.
Miscellaneous	
RLY1	DPST or DPDT relay, 5A-rated contacts with 12 V coil (120 ohms or greater).
PB1	momentary action pushbutton (e.g: D.S.E. S-1102, S-1199 types, or similar).

ETI-323 pc board; five-way plastic terminal block; box (if necessary); wire etc.

Price estimate
$14 — $16



Artwork. If you want to make your own pc board, a same-size negative or positive transparency can be had for $1.00, post paid, from:
ETI-323 Artwork
ETI Magazine
140 Joynton Ave
Waterloo NSW
Make cheque or money order out to 'ETI Artwork Sales'. Ensure you ask for **positive** or **negative** according to your requirements.

Component overlay and external wiring. How the parts are assembled onto the printed circuit board — watch which way around you assemble D2, IC1 and C2. Wiring to the external components is also shown. The pc board and relay may be housed in any suitable box, if you wish.

Construction

The unit is easy to build and install and works off the car's 12 V battery. The circuit does not interfere with normal headlight operation under actual driving conditions.

Construction is simple because there are only a few components and the layout on the pc board is clearly shown. Before you assemble the components on the board, check that the board has no track breaks or shorts between the tracks, particularly between the IC pins. Make sure you solder the diodes the correct way round.

The relay can be any 12 V DPDT (double-pole, double-throw) type with a coil resistance of 120 ohms or greater. The contacts should be rated to switch 5 A or greater at 12 Vdc. Note that the IC, a 555, is shown on the circuit diagram with all its connections in the standard manner. Look for the notch and make sure that it's positioned on the pc board correctly, soldering it in after the other components.

Kits and components. See 'Shoparound' in this book to find suppliers stocking kits or components for this project.

HOW IT WORKS — ETI-323

This circuit has been designed around the 555 IC timer which has already been described.

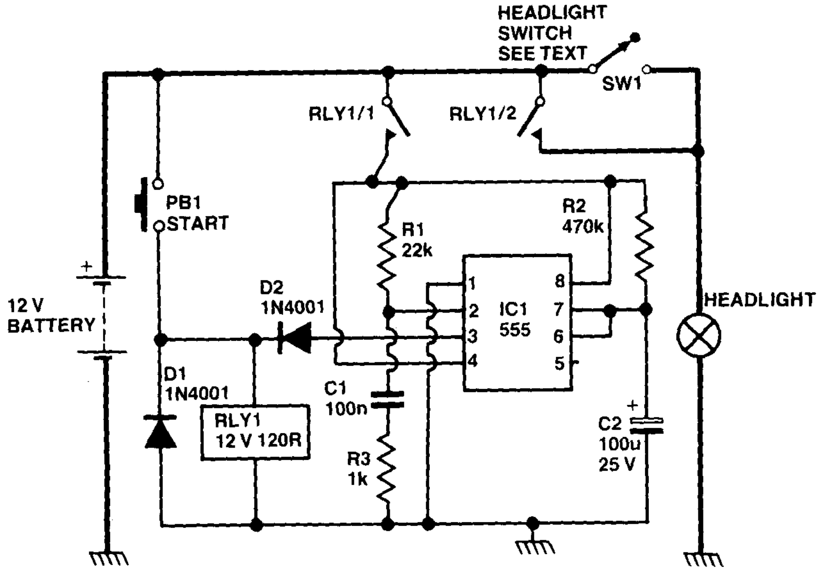
The pin 3 output is connected to a relay which has two sets of normally open contacts. D2 is wired in series with the relay coil to counteract the slight residual voltage that appears at pin 3 of the IC under the OFF condition and this makes sure that the relay turns fully off. The START switch, PB1, is also normally open so there's no power going to the timer circuit and the lights are off. Capacitor C1 is discharged under this condition.

When PB1 is momentarily closed power is fed directly to the relay coil and the relay turns on. As the relay turns on, contacts RLY1/2 close and apply power to the vehicle lights and contacts RLY1/1 close and apply power to the timer circuit. At this moment pin 2 of the IC is briefly tied to ground via C1 and R3 so a negative trigger pulse is immediately fed to pin 2 and a timing cycle is initiated.

Consequently, pin 3 of the 555 switches high at the moment that the relay contacts close, and thus locks the relay into the ON *condition* irrespective of the subsequent state of the PB1 START switch so the lights remain on for the duration of the timing cycle.

The period of the timing cycle depends on the values of R2 and C2. With the component values shown, this period is roughly 50 seconds.

At the end of the timing cycle pin 3 of the IC switches to the low state, so *the relay turns OFF and* contacts RLY1/2 and RLY1/1 *open,* disconnecting power from the timing circuit and the lights. The operating sequence is then complete.



Circuit diagram. The parts in the shaded area are located on the pc board.

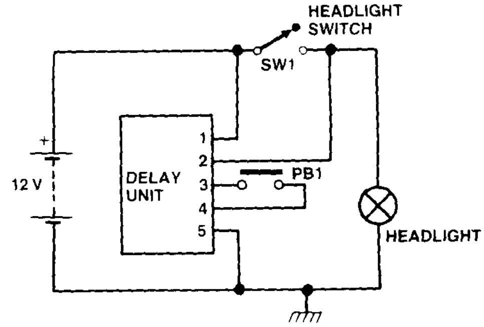


Figure 3. Connection of the delay unit to a car system where the headlights are independent of the ignition switch.

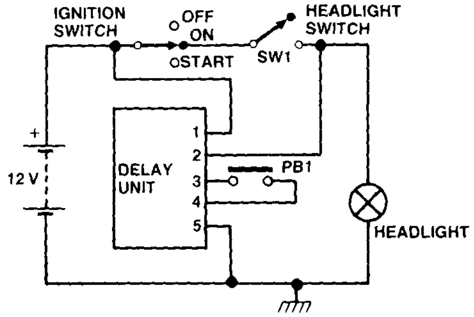
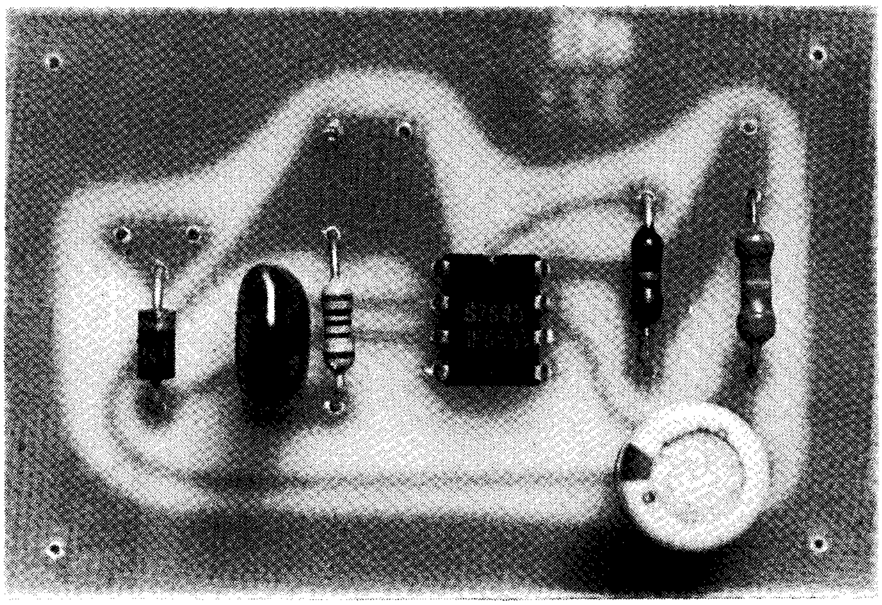


Figure 4. Connection to all other systems.

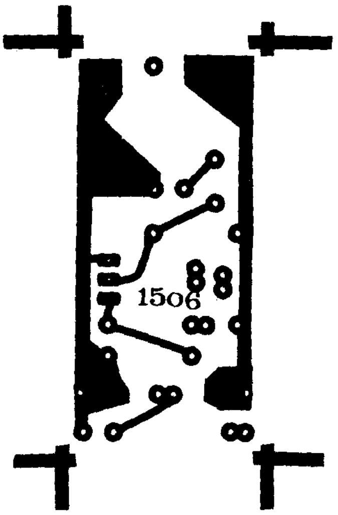


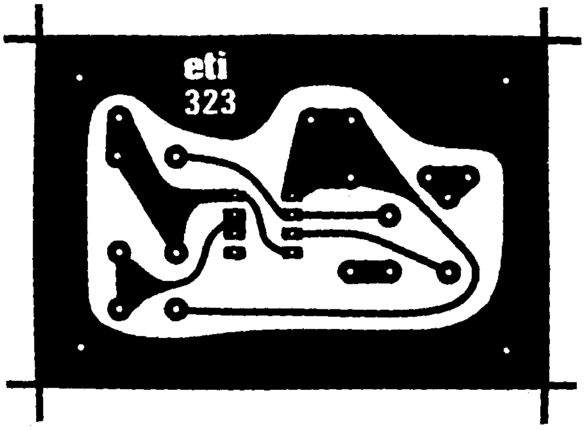
Closeup. View of the assembled printed circuit board, about four times life size!

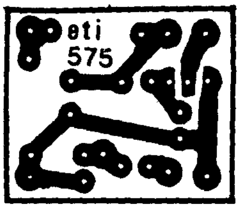
When it comes to installing the unit, note that two methods of connection to the vehicle are possible. On some vehicles the headlight switch is connected directly to the battery so that the headlights operate even when the ignition is turned off (see Figure 3).

Many vehicle manufacturers are now adopting the practice of feeding the headlight switch via the ignition switch, so that the headlights operate only when the ignition is turned on. If your car uses this type of connection then you'll have to install the unit as shown in Figure 4. ●

PCBs







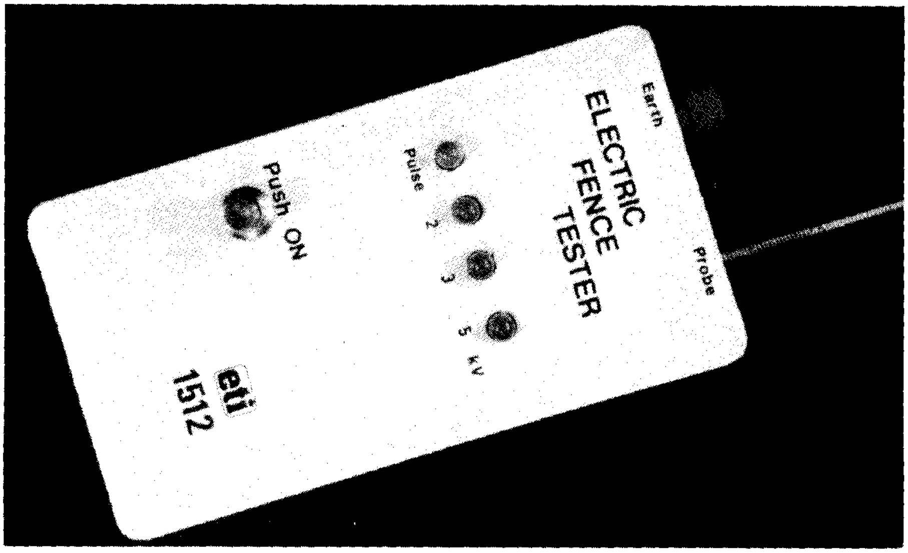
Electric fence tester

This project was developed to take some of the guesswork out of testing or checking an electric fence. Many factors can influence the operation of an electric fence energiser and fence, reducing its effectiveness. A common method of testing a fence is to hold a blade of grass near the wire and get the 'feel'. Get it wrong and you'll find yourself dusting off the seat of your pants!

Graeme Teesdale

ELECTRIC FENCES are now a common 'tool' of farm management. Cattle which escape from an enclosure can cause considerable injury to themselves and other property. An electric fence is an effective, non-injurious barrier when properly erected and maintained. But they have to be maintained! Checking if an electric fence is operating by grabbing it is one method to prove it's working — but few relish the substantial 'jolt' delivered. Another method is to hold a blade of grass near the fence wire. At a few centimetres distant, you should feel a 'tickle'. But, that's dependent on the moisture in the grass, your contact with the ground, etc. If you fail to feel the tickle and approach more closely, you're liable to receive quite a jolt! None of these methods is quantitive, nor can results be compared day-to-day or along the length of a fence.

This project was devised to provide a more quantitive indication of fence/energiser operation and avoid the pitfalls of the 'grass roots' methods.



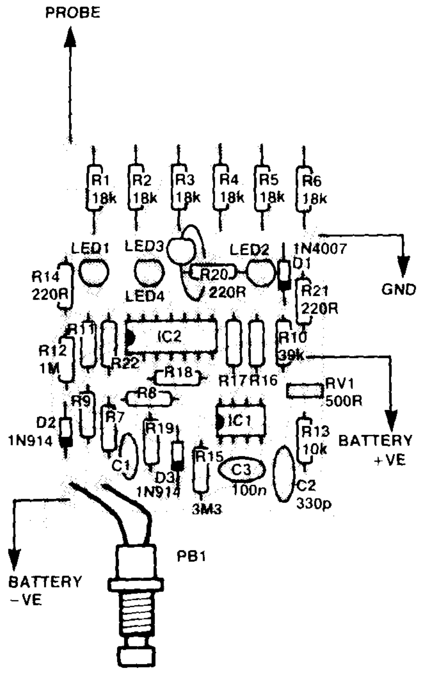
The unit indicates the presence of each pulse from the energiser and shows when the pulse voltage on the fence wire exceeds an amplitude of 2 kV, 3 kV and 5 kV, once calibrated. If used in an uncalibrated mode, the unit will indicate pulse amplitudes on the fence of 40%, 60% and 100% of energiser output.

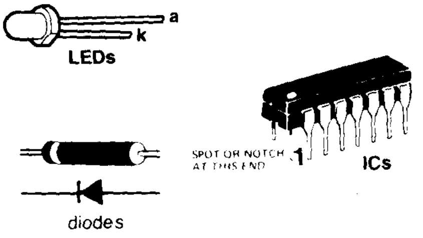
The electronics for this project has been deliberately kept simple, so that the cost is low and reliability good. Construction, too, is simplified. Only two ICs, a handful of resistors and capacitors, four LEDs and very little else is used. The LEDs are used as indicators. So that they can be readily seen in sunlight, we recommend you use the common yellow LEDs or the recently introduced 'high brightness' types.

Our tester was housed in an all-plastic case — so that you can't possibly come in contact with anything carrying the high voltage pulses! The case is held in one hand and the probe protruding from the end touched on the live wire from the fence after the 'ground' probe or lead is literally 'earthed'. Pressing the pushbutton on the front panel turns the unit on. One LED indicates the presence of a pulse. The '2 kV' LED lights to indicate the unit is on and goes out when a voltage pulse exceeding 2 kV is present. When the voltage pulse exceeds 5 kV, the 2 kV LED goes out and the '3 kV' and '5 kV' LEDs flash on. If there is a problem with the fence or the energiser, and the voltage does not exceed 2 kV, the 'pulse' LED only will flash, indicating that the energiser is working but that the voltage is low. More details on checking out a fence are given later.

Construction

For ease of assembly and reliability, it is recommended you use our pc board design. This board will fit in a standard, commonly stocked plastic case measuring at least 60 mm wide by 30 mm deep by 110 mm long. A number of models have been made, but the one shown in the photograph measured 65 x 36 x 121 mm (w-d-l). The front panel was dressed up with a *plastic* Scotchcal label. Don't use a metal type as pulses from the fence probe may 'track' across the case to the panel and you may receive a little surprise. You can make your own pc board using our artwork or buy one ready made, that's up to you. ▶





PARTS LIST — ETI-1512

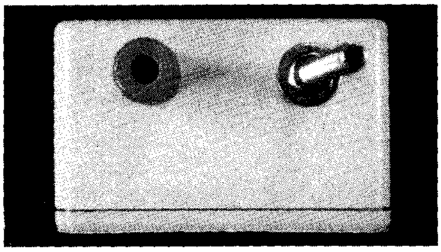
Resistors	all ½ W, 5% unless noted
R1-6	18k, 1 W
R7, R12	1M
R8, R15	3M3
R9	100k
R10	39k 1 W
R11	2M2
R13	10k
R14, 20, 21, 22	220R
R16	4k7
R17, R19	2k2
R18	1k2
RV1	500R min. vertical mount trimpot.
Capacitors	
C1, C3	100n greencap
C2	330p ceramic
Semiconductors	
D1	1N4007
D2, D3	1N914, 1N4148
IC1	CA3140
IC2	LM324, uA324
LED1-4	TIL220Y yellow LEDs
Miscellaneous	
PB1	pushbutton

ETI-1512 pc board; all plastic zippy box 121 x 65 x 36 mm or similar; No. 216 9 V battery and clip lead; Scotchcal front panel; wire, alligator clip etc.

Price estimate
$18 — $22

When you've gathered all the components together, first thing to do is check the pc board. See that all the holes are drilled the correct size and that there are no broken tracks or shorts between tracks — particularly between the IC pins. Commercially made boards don't suffer such problems in general, but do check the hole sizes. If you mount the pushbutton switch on the pc board, like I did, then see that the holes where it mounts are of the right diameter. Leads on the LEDs on the trimpot are usually of greater thickness than most other components and their mounting holes should be checked too.

At the 'top' of the case, mark out and drill two holes for the fence and ground probes. The fence probe shown on the model in the photographs was a 50 mm long 2 BA bolt. The ground probe was plugged into a standard 'banana' socket.



Top. Fence probe and ground socket.

If, or when, all's well with the pc board, mark out and drill the case. Tackle the front panel first. You can use the Scotchcal artwork as a template to mark out the front panel, pricking through the artwork with a sharp-pointed instrument such as a scriber. Drill the holes carefully. It's easier to use the lid of the plastic case as the front panel. No clip holders for the LEDs were used as they're unnecessary, really. Just drill the LED holes slightly larger than the diameter of the body of the LED — 5 mm will do nicely. The pushbutton will require a 6.25 mm (¼") hole.

Now you can put the Scotchcal on the front panel. Position it carefully, having peeled away the backing. When you've got it in position, smooth it down rubbing from the middle toward the edges, taking care to avoid getting bubbles under it. If you do get some bubbles or small wrinkles, these can be smoothed out by rubbing them away towards the nearest edge. Using a modeller's scalpel or other sharp blade, carefully cut out the holes in the Scotchcal.

With the case prepared, you can tackle the pc board assembly. Refer to the accompanying overlay. Solder all the resistors and capacitors in place first, including RV1. Then solder all the diodes in place, making sure you get them the right way round. Note that D1 is a 1N4007 and D2, D3 are 1N914s or 1N4148s. Solder the two ICs in place next, taking care to orient them correctly. Solder the pushbutton to the board next, making sure it sits perpendicular to the board. Last of all come the LEDs. Place them in their positions, making sure you get them the right way round, but don't solder the leads yet. Temporarily mount the board to the panel using the pushbutton. Then, pushing each LED into place in turn, solder their leads to the board. Disassemble the board from the front panel and solder flying leads of adequate length from the fence probe and ground probe pads on the board and attach the battery clip lead. Use heavily insulated wire for the probe leads and space them well away from each other.

Assemble the board to the panel once again and terminate the two probe leads from the board. Plug in a No. 216 9 V battery and you're ready to test and calibrate the unit.

Testing it

This method is guaranteed non-dangerous as you don't get anywhere near an electric fence or fence energiser! For this test you will need one 470 ohm resistor. Solder one lead to the battery positive pad on the board. Set RV1 so that its wiper is at the R10 end of its travel (toward IC1). Press the pushbutton. The '2 kV' LED should come on. Now touch the other end of the 470 ohm resistor to the junction of R10 and RV1. The '2 kV' LED should go out, the '3 kV — 5 kV' LEDs should light and the 'pulse' LED should give a flash. When you disconnect the 470 ohm resistor, the '3 kV — 5 kV' LEDs should go out in reverse order (5 kV LED first) and the 2 kV LED light briefly. If you don't get these indications, look for an error in component orientation or placement. Check that you're getting the supply to the circuit when you press the pushbutton, too.

Correct any errors and try again.

Calibration

You can go about this in several ways. The display can be calibrated to read fence voltage as a percentage of energiser voltage output or it can be calibrated to read directly in volts.

If you're going to calibrate the display to show percentage of energiser output then this should be done with the energiser connected to either a 'known good' fence or to a ▶

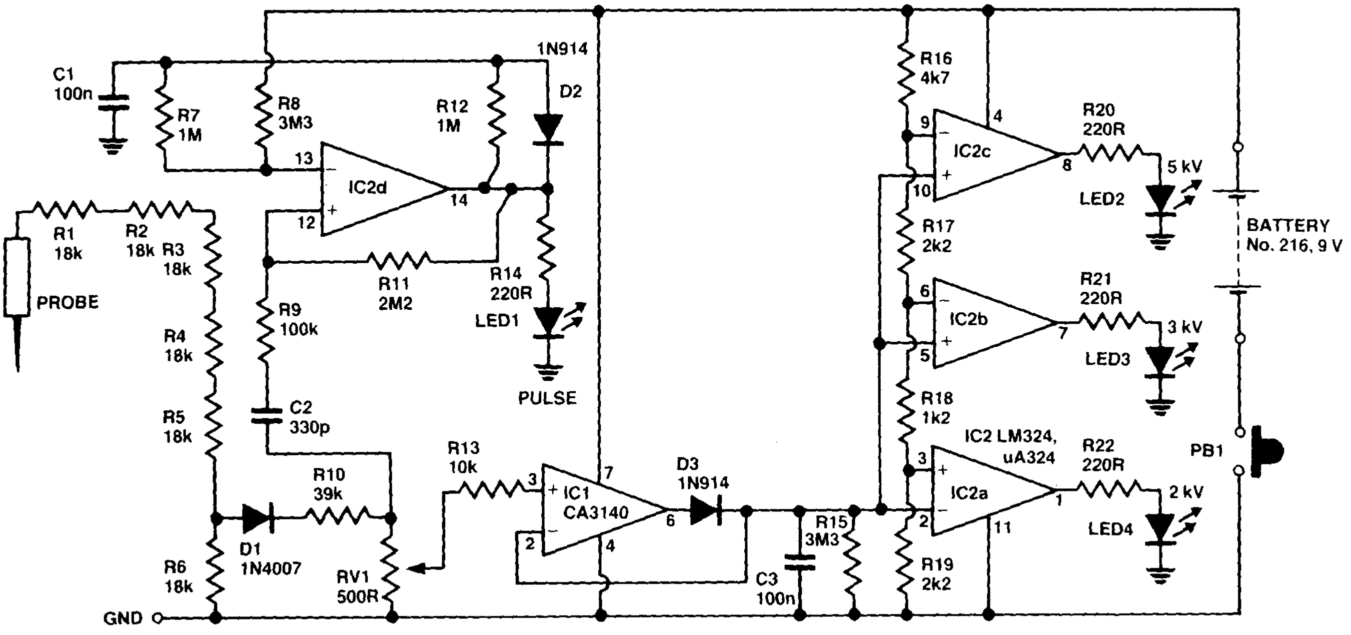
RESISTORS R1 TO R6 AND R10

These seven resistors require special mention. In use, they will experience a pulse voltage across them of around 800 to 1000 volts. Power dissipation will never be a problem as the pulse duration is too short and pulse timing too long to cause any significant dissipation.

However, all resistors have a voltage stress rating for both continuous operation (max. dc working voltage) and for pulse operation. The reaction of resistors to voltage stresses is almost instantaneous. Carbon film resistors — commonly stocked by component suppliers — can withstand about twice to 2.5 times their rated dc working voltage under pulse conditions. A 1 W carbon film resistor generally has a dc working voltage of 500 V and thus will withstand 1 kV to 1.25 kV under pulse conditions. Thus, we recommend resistors of 1 W rating for R1 to R6 and R10.

At a pinch, ½ W resistors could be used. These generally have a dc working voltage rating of 350 V and, at best, will withstand 875 V under pulse conditions.

(For more information, see *Resistors* and *Film Resistors*, by Roger Harrison, ETI September '76 page 90 and November '76 page 15, respectively.)



HOW IT WORKS — ETI 1512

The circuit can be divided into four sections: the input divider, the peak voltage detector, the display and the pulse indicator.

INPUT DIVIDER

The input divider comprises R1 to R6, plus R10 and RV1. Diode D1 is for protection, and I'll get around to that shortly. Assuming a positive-going input pulse of 5 kV peak, the voltage appearing across R6 will be about 830 V. This will be conducted to R10/RV1 via D1 and a pulse of about 10 V peak will appear across RV1. When calibrated to indicate voltage on the display LEDs, RV1 will be set to about mid-travel and a pulse of about 5 V peak will appear on the wiper of RV1. What happens to that, I'll get around to in a minute, but first, what's the reason for D1?

Should the input pulse on the fence probe be negative-going, as it sometimes is, then D1 will not conduct as it will be reverse-biased. This prevents a large negative-going pulse being conducted to the rest of the circuit. If the peak pulse voltage developed across R6 in this situation should be greater than 1000 volts, D1, which is rated at 1 kV PIV, will likely go into reverse, or 'zener', breakdown the current passed through it being limited by R10. The voltage across RV1 will be very low, thus ensuring the rest of the circuit is still protected.

PEAK VOLTAGE DETECTOR

IC1 and D3 are arranged as a peak voltage detector. The positive-going input pulse from RV1 is applied to the non-inverting input of IC1, pin 3, via R13. As the input impedance of IC1 is very high, R13 does not drop the input voltage and simply provides input current limiting. The output of IC1 will be driven toward the positive supply rail and D3 will conduct. Negative feedback from the cathode of D3 to the inverting input of IC1, pin 2, ensures that IC1 has only unity gain (x1). The output of IC1 charges C3 to the same value as the peak voltage applied to the input. If the peak pulse voltage on the fence probe is 5 kV, and the voltage on the wiper of RV1, when calibrated, is 5 V then C3 will be charged to 5 V.

When the input pulse falls to zero, C3 will discharge slowly via R15 and the combined input impedance of op-amps IC2a, b and c.

THE DISPLAY

The display circuitry consists of IC2a, b and c arranged as voltage comparators, LEDs 2, 3 and 4 and resistors R16 to R22.

The resistive divider formed by R16, 17, 18 and 19 provides three fixed voltage points. The junction of R16-17 will be at 5 V (with respect to the common rail), the junction of R17-18 will be at 3 V and the junction of R18-19 will be at 2 V. Thus the inverting input of IC2c will be held at 5 V, the inverting input of IC2b will be held at 3 V, but the non-inverting input of IC2a will be held at 2 V.

With the non-inverting input of IC2a (pin 3) held at 2 V, the output, pin 1, will be driven high (toward +9 V) and LED4 will light, the current through it being limited by R22. That is, assuming PB1 is pressed! LED4 thus acts as an 'ON' indicator, one part of its dual role.

If the voltage on C3 reaches a little over 2 V, the inverting input (pin 2) of IC2a will cause the output to go low and LED4 will go out, indicating that the peak pulse voltage on the fence probe has reached 2 kV.

As the inverting inputs of IC2b and c are held at a lower voltage than their non-inverting inputs, the outputs of these two op-amps will be low and LEDs 3 and 4 will be off.

When the voltage on C3 reaches a little over 3 V, the non-inverting input of IC2b will be at a higher voltage than its inverting input and its output, pin 7, will be driven high, lighting LED3. Note that LED4 will remain off. Thus, LED3 lighting indicates that the peak pulse voltage on the fence probe has reached 3 kV.

When the voltage on C3 reaches a little over 5 V, the non-inverting input of IC2c will be higher than its inverting input and LED2 will be turned on, in the same way as LED3 was turned on. Thus, when LED2 lights, you know the peak pulse voltage on the fence is at least 5 kV. Note that, in this case, LED4 will be out and LEDs 2 and 3 will be lit.

The pulse from the fence falls to zero very rapidly, but the charge on C3 will be maintained, slowly leaking away via R15 and the combined input impedances of the op-amps IC2a, b and c. Thus, the display will 'hold' for longer than the duration of the fence energiser pulse, allowing you to see the action more readily.

THE PULSE INDICATOR

This circuit comprises IC2d, LED1 and associated components. The input pulse is used to trigger IC2d which is connected as a one-shot multivibrator. The output of IC2d drives LED1 which will flash, indicating the presence of a pulse, regardless of the amplitude, so that if the pulse has insufficient amplitude to drive LED4 off, you can still check that the energiser is supplying pulses to the fence.

In the absence of an input pulse, resistor R8 keeps the output of IC2d in a low state (0 V) as it holds the inverting input (pin 13) at a higher voltage than its non-inverting input (pin 12). Thus, LED1 will be off.

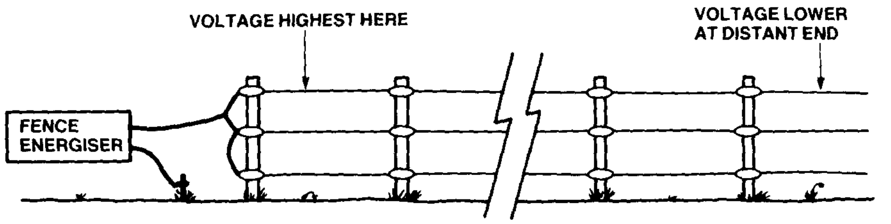
When an input pulse arrives, it is coupled to the one-shot via C2, and R9. The positive-going pulse drives the non-inverting input of IC2d (pin 12) more positive than its inverting input (pin 13), driving the output (pin 14) high. LED1 will turn on and positive feedback via R11 will cause IC2d to 'latch' in this state. At this time, C1 will charge from virtually zero volts towards the supply rail, via R7-R8. When the voltage across C1 reaches the value on pin 12, the op-amp will switch back to its previous state with the output low. LED1 will then go out. This action takes a few hundred milliseconds, time enough for you to see LED1 light.

So that the one-shot reacts to rapid pulses, diode D2 is included to discharge C1 quickly, so that IC2d rapidly resets to its quiescent state, ready to receive the next incoming pulse.

If the energiser provides a negative-going pulse to the fence, reverse the energiser connections, NOT the Fence Tester connections or you'll be applying the fence pulse to the common rail of the Tester and you might get a wee surprise via PB1 when you try to test the fence.

Shock. Horror. Probe! Gentleman about to receive shock from incorrectly connected Fence Tester (note ground lead going to live fence wire!).

dummy fence'. A dummy fence can be made up quite simply. You'll need two 10n/3 kV ceramic capacitors, which are widely available. These should be connected in series and then connected directly across the energiser output along with the Fence Tester, thus placing a load of about 5 nF on the energiser. Nothing else should be connected across the energiser output. Make sure all the connections are well above the bench top, or whatever. Set the energiser going, then press the pushbutton on the Fence Tester. Adjust RV1 back until the '5 kV/100%' LED just goes out, then advance it until it comes on again with each pulse. This doesn't necessarily indicate that the energiser is delivering 5 kV. Some energisers will only provide an output around 4 kV on load. This procedure assumes your energiser is working correctly in the first place, so you'd better be pretty sure of that!



Indications. An electric fence doesn't deliver the same 'punch' over its entire length. This diagram shows you what to expect.

By far the best method is to calibrate the Fence Tester so that it actually indicates voltage. For this you'll need an oscilloscope with a x10 or x100 probe. Set the Y-input attenuator to read 200 volts/div. (i.e: 2 V/div. or 20 V/div., depending on what range the input attenuator covers). Connect the CRO input across R6 and set the sweep to a low rate. Set the Y-amp input to 'dc'.

Again, your energiser should be connected either to a known good fence or a dummy fence. Connect the Fence Tester to the energiser's output, set the energiser going, and measure the pulse amplitude directly from the oscilloscope's face. At 200 V/div., multiply by six to give the energiser's output directly in volts. Say you get a pulse amplitude of 4½ divisions on the CRO. The energiser's output is 4.5 x 200 x 6 = 5400 volts.

Note the polarity of the pulse. Generally, it will be positive-going. However, some energisers give a negative-going pulse. If such is the case, you'll need to reverse the energiser output leads for the next step.

This time, connect the oscilloscope across C3. (Don't use a x1 probe or you'll upset the C3-R15 time constant.) Set the Y-input to read, say, 1 V/div. on the screen (taking the probe division into account). Turn on the energiser and adjust RV1 so that the peak pulse voltage on the screen is 1000th that previously determined. If the energiser output was determined to be 5400 volts, then the peak pulse amplitude across C3 should be 5.4 volts when RV1 is correctly adjusted.

The unit is now calibrated and ready to use.

In use

When using the Fence Tester, *always* remember to *connect the ground probe first.* You can use a pointed metal stake to drive into the ground or a large, strong alligator clip to get a good 'bite' on the star pickets often used to support elecric fences. Touch the fence probe on one of the 'live' fence wires and then press the pushbutton. Keep your hands and the Tester dry and keep your big fat pinkies away from the top end of the box.

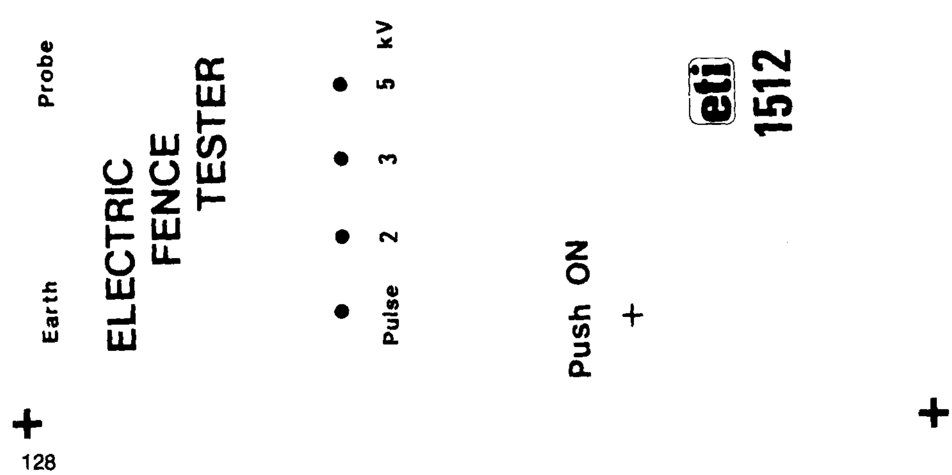
You will find that the voltage on the fence will be highest closest to the energiser, decreasing the further down the fence you move from the energiser end. If the fence is 'shorting to ground' somewhere, then the voltage will fall off rapidly as you approach the fault. If the live wire is open (i.e: broken) at some point, the voltage will remain high within the vicinity of the break, but disappear on the side of the break away from the energiser.

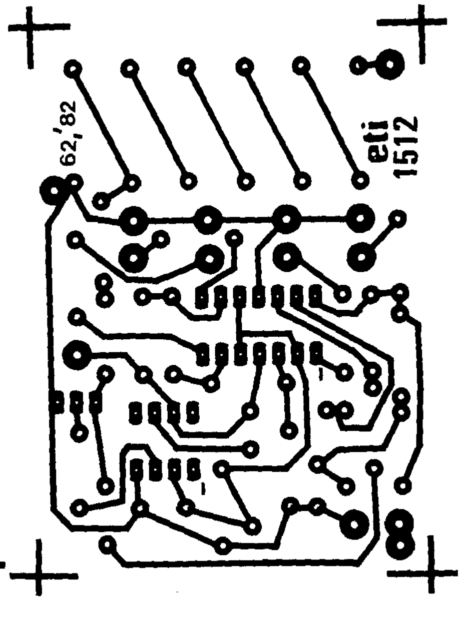
To be effective, the fence voltage should be generally no lower than 3 kV at its distant end. ●

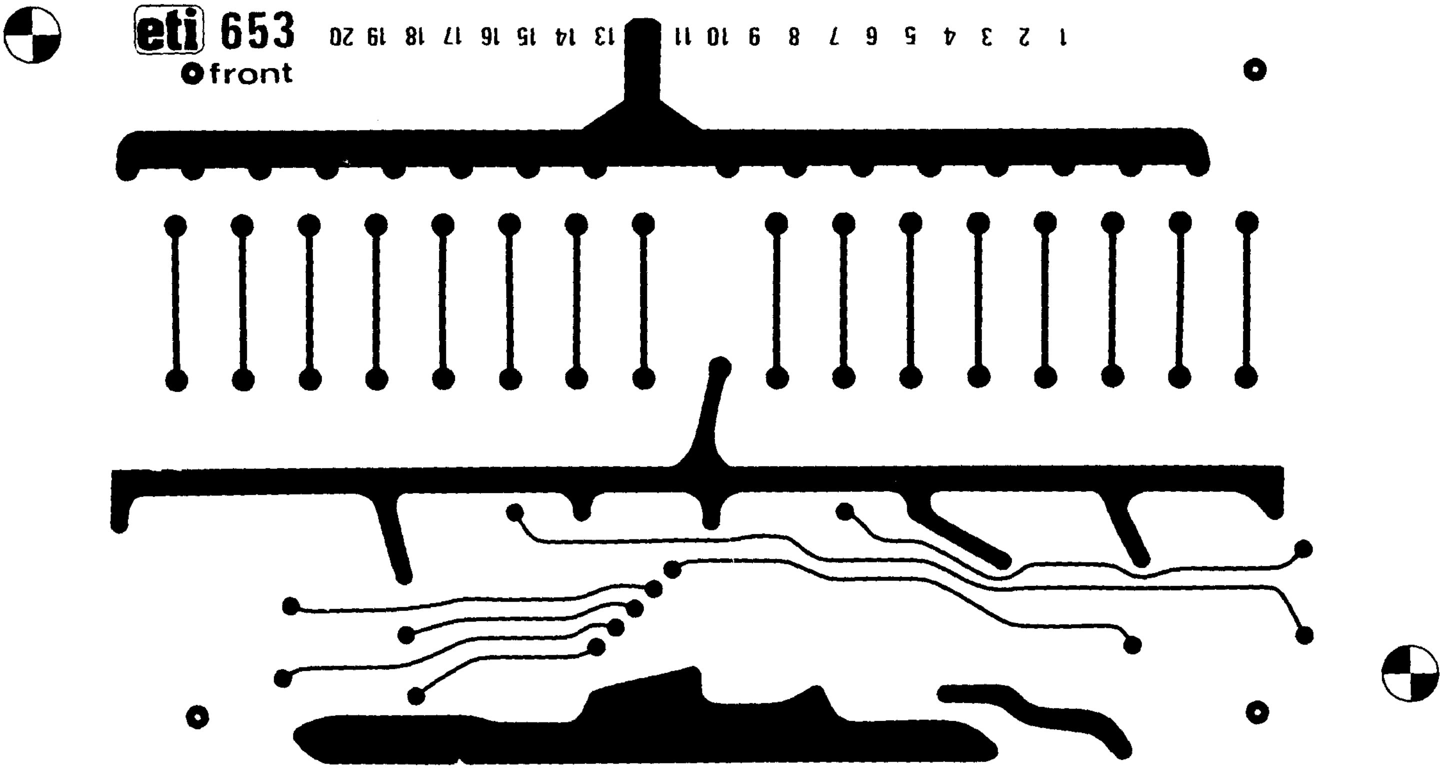
BATTERY CHOICE

As this project will probably experience considerable periods of idleness, a battery having a long shelf life is recommended. Alkaline batteries have by far the longest shelf life, being about two years, and are thus recommended. Standard carbon-zinc batteries have a shelf life somewhat less than half that of Alkaline types and would need replacing at six to eight month intervals — if you could remember!

Artwork. Full size reproductions of panel and pc board artwork.



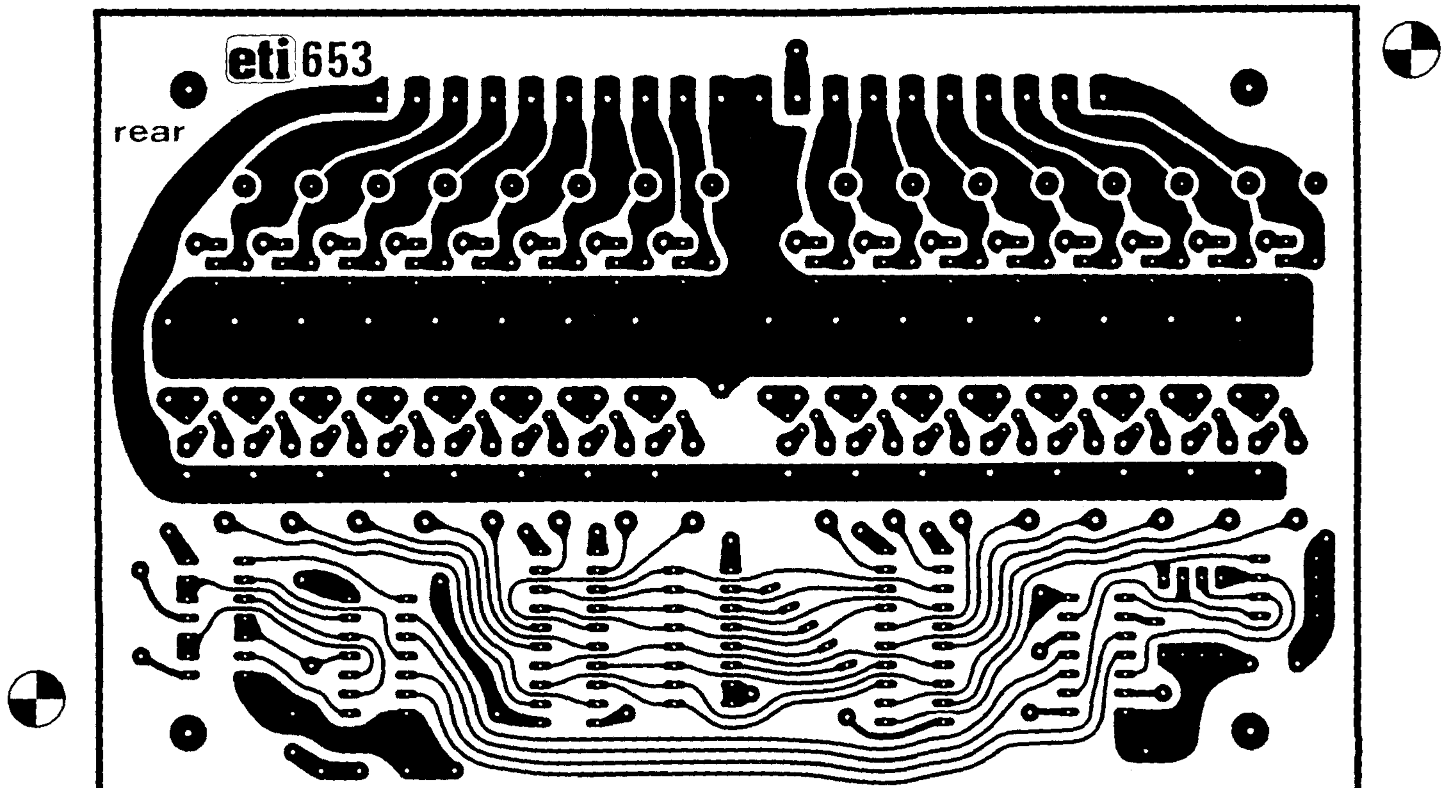




NOTE:
The address line inputs are connected to CMOS gates. This means that the address lines from the computer should be buffered with CMOS drivers to ensure that the high level voltage is above the switching threshold.

However, if a TTL driver is used, such as a 74LS374 etc, pull-up resistors should be used to raise V_{OH} to the CMOS specification. A pull-up of about 220 ohms is sufficient.

The resistors may be conveniently mounted between IC4 and the DIL input socket on the component side of the pc board. There are five feed-through links in a diagonal pattern between IC4 and the input socket. Remove these and install the five resistors, bending them towards the copper area at the bottom of the board. Solder the resistor' leads through the feedthrough link holes on both sides of the board and solder the other ends to the copper area (+5 V rail). Murphy — go suck eggs!



SHOPAROUND

This page is to assist readers in the continual search for components, kits, printed circuit boards and other parts for ETI projects and circuits. If you are looking for a particular item or project and it is not mentioned here, check with ETI advertisers.

ETI-145 prototyper

Kits are available from All Electronic Components, Rod Irving Electronics and Altronics. Intersil, who make the ICL7660, are represented in Australia by R&D Electronics, 133 Alexander St, Crows Nest NSW 2065, and 257 Burwood Hwy, Burwood Vic. 3125.

The breadboard strip used in this kit is available in a variety of configurations from a wide range of suppliers. The Atek AT-2N is handled by Emona Enterprises, CBC Bank Building, 661 George St, Haymarket, Sydney. (02)212-4815. Radio Parts handle the Atek breadboards in Melbourne, Radio Despatch Service in Sydney. The Continental Specialities breadboard is available from a variety of suppliers.

ETI-160 13.8 V/10 A supply

Kits are available from Altronics, All Electronic Components, Dick Smith Electronics and Rod Irving Electronics. Parts are generally common; the K&W case is actually C1066, not C1064 as originally stated.

ETI-161 LCD panel meter

Kits are available from Dick Smith Electronics, Rod Irving Electronics and All Electronic Components. The Intersil parts can be obtained from All Electronic Components in Victoria or R&D Electronics.

ETI-162 30 V/1 A supply

All parts are commonly available off the shelf. Kits may be obtained from Altronics, Jaycar, Rod Irving Electronics, All Electronic Components, Electronic Agencies and Dick Smith Electronics.

ETI-163 lab. supply

Every hobbyist's workshop, technician's bench or engineer's lab. should have one! Kits are available from Altronics, Jaycar and Rod Irving Electronics. You could also try All Electronic Components.

The transformer is made by Permatran in Melbourne and Ferguson Transformers in Sydney, type No. PF4673 (which complies with Australian Standard AS3126).

The Scotchcal panel and meter labels and the pc board can be obtained from the suppliers listed at the end of this column.

ETI-164 zener tester

The components are commonly available and several models of the 'transistor audio transformer' were tried out in the prototypes and all worked well. Suitable 1k CT to 8 ohm transformers are available from many suppliers. Dick Smith Electronics lists one as cat. no. M-0216; Altronics has the M0216 and M0226 which are both suitable; Tandy lists one as cat. no. 273-1380. Rod Irving Electronics and All Electronic Components have kits.

ETI-268 NiCad 'float' charger

Kits for this should be available from Altronics, Dick Smith Electronics, Jaycar, Rod Irving Electronics, Electronic Agencies and possibly All Electronic Components. However, all parts are readily available items with perhaps the exception of the LM336. This is distributed by N.S.D. and Semtech. Radio Despatch, Rod Irving Electronics, Jaycar and Electronic Agencies generally keep stocks, though.

ETI-323 headlight delay

For a kit of this project, try All Electronic Components or Rod Irving Electronics. The few parts are all common off-the-shelf items and printed circuit boards can be obtained from the suppliers listed at the end of the column.

ETI-330 car alarm

This is widely stocked as a kit. Try Altronics, Dick Smith Electronics, Rod Irving Electronics, Jaycar, All Electronic Components and Electronic Agencies. Parts are generally available and pc boards can be obtained from the suppliers listed later.

ETI-334 auto-tester

All parts are standard and can be easily obtained off-the-shelf. Kits will be stocked by All Electronic Components, Altronics and Rod Irving Electronics.

ETI-335 pushbutton wiper controller

Kits for this may be obtained from All Electronic Components and Rod Irving Electronics. Printed circuit boards are available from the suppliers listed later and all the components are widely available.

ETI-461 balanced amp

Kits for this project are stocked by Altronics, Jaycar, Rod Irving Electronics, Electronic Agencies, and you could also try All Electronic Components. The printed circuit board is stocked by the suppliers listed later and all the parts are widely available.

ETI-494 speaker protector

Kits are available from Altronics, Electronic Agencies, Jaycar, Rod Irving Electronics and All Electronic Components. All parts are readily obtainable and printed circuit boards can be obtained from any of the suppliers listed at the end of this column.

ETI-570 infrared trip relay

Rod Irving Electronics can supply a kit for this and possibly All Electronic Components. As is our usual practice, parts are commonly available and pc boards can be obtained from the suppliers listed later.

ETI-1505 fluoro inverter

Kits should be obtainable from Altronics, Dick Smith Electronics, Rod Irving Electronics and All Electronic Components. The EC core assemblies are distributed by both Philips Elcoma and Siemens. The George Brown group can supply them.

ETI-1506 xenon bike flasher

'Short form' kits for this may be obtained from Rod Irving Electronics and perhaps All Electronic Components. Suppliers of the printed circuit boards are listed later.

ETI-1508 train controller

Kits, generally in 'short form', can be obtained from Altronics, Jaycar, Rod Irving Electronics and All Electronic Components. See the list at the end of this column for printed circuit board suppliers, and most of the component suppliers listed there, too, should stock the required components.

ETI-1509 dc-dc converter

Any of the following suppliers should be able to sell you a kit for this useful project: Altronics, Electronic Agencies, All Electronic Components, Rod Irving Electronics and Dick Smith Electronics. The FX2242 potcore assembly is widely stocked. The EC core assembly is the same as used in the ETI-1505 Fluorescent Light Inverter, distributed by Siemens and Philips Elcoma. George Brown stocks them.

ETI-1510 points controller

The same goes for this as for the ETI-1508 above.